NASA TECHNICAL MEMORANDUM

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SPACE SHUTTLE SOLID ROCKET BOOSTER COST-PER-FLIGHT ANALYSIS TECHNIQUE

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SPACE SHUTTLE SOLID ROCKET BOOSTER COST-PER-FLIGHT ANALYSIS TECHNIQUE

I. INTRODUCTION

The hardware design, operational planning and budgeting of a space transportation system to minimize recurring cost presents a formidable challenge. Figure 1 depicts the Solid Rocket Booster (SRB), the most expensive recurring cost element of the Space Shuttle. Cost must be considered as a hardware design and operational planning parameter having equal status with performance and schedule. A Cost-Per-Flight (CPF) computer model (Fig. 2) developed for the SRB project is described which allows the interaction of performance, operational planning groundrules, and cost to be assessed. On a regular basis the model is used to provide status estimates of CPF and real-year cost to operate the SRB project. Cost impact assessments are performed for proposed changes in Space Shuttle program and SRB project groundrules. Through sensitivity and trade studies, opportunities for cost-effective program decisions have been found. The overall CPF model consists of a series of computer programs which perform hardware logistics simulation, CPF analysis and real-year cost analysis (See Tables 1 through 5). The development and use of the computer programs is described. A general description of the SRB is given in Reference 1.

A. Logistics Simulation

The reuseability feature of the SRB design has several implications for the planning and scheduling of those resuses. Individual components can be used different numbers of times. It takes different amounts of time to refurbish and make ready for the next flight various components. In addition, attrition (defined as the probability that a piece of hardware will be lost or irrepairably damaged during a reuse cycle) can occur during transportation, launch operations, flight. recovery or refurbishment. Under these circumstances, reuse planning can be performed on either a deterministic or a probabilistic basis. A deterministic approach implies selection of the reuse cycle on which each component is assumed to be lost. A probabilistic approach implies allowing the losses to occur randomly among the reuse cycles, i.e., on each use cycle a chance is taken of losing the component. Although some deterministic planning is done, the fact that attrition is expected to be random leads to a probabilistic approach being more realistic.

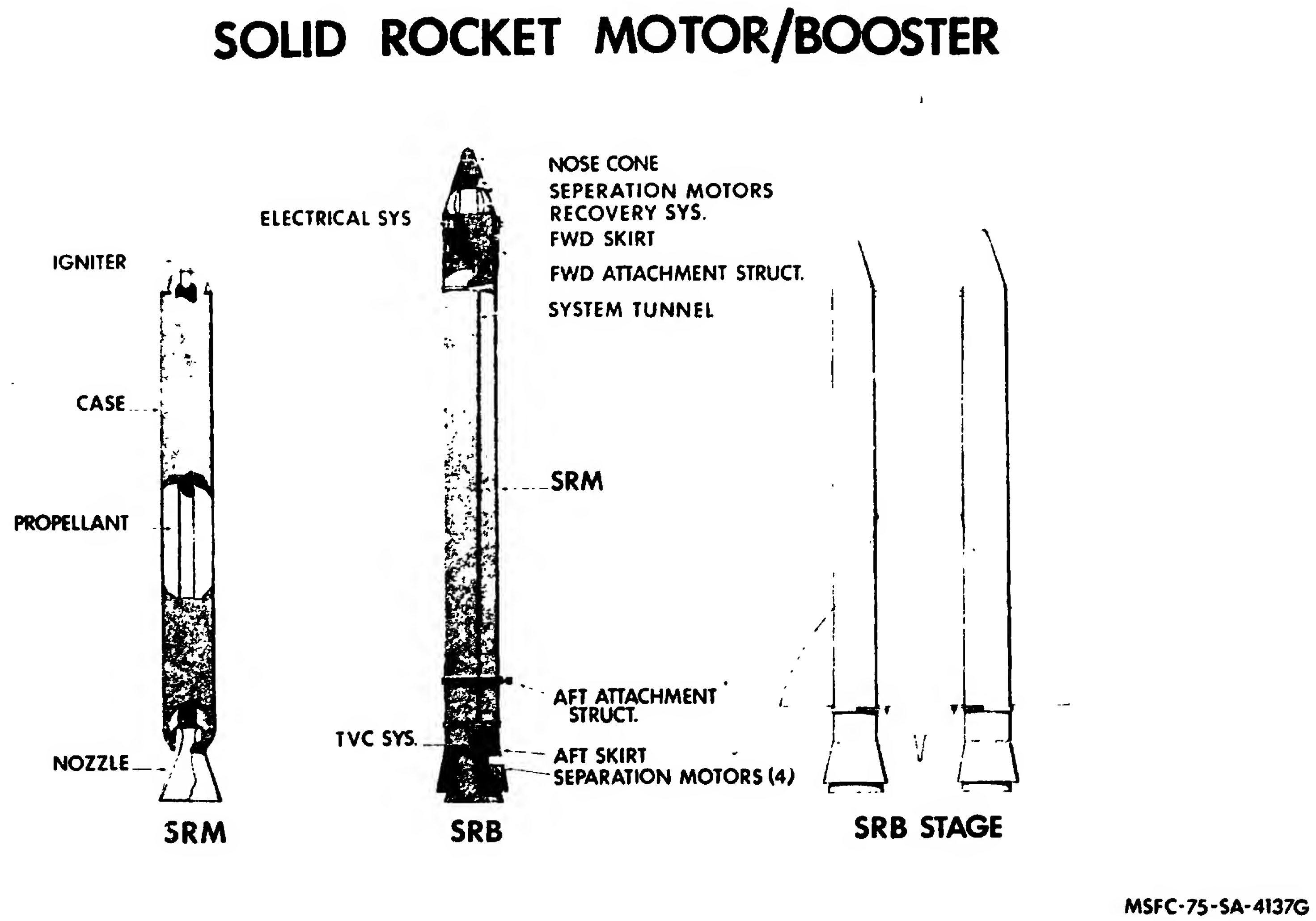


Figure 1. Solid Rocket Booster for Space Shuttle.

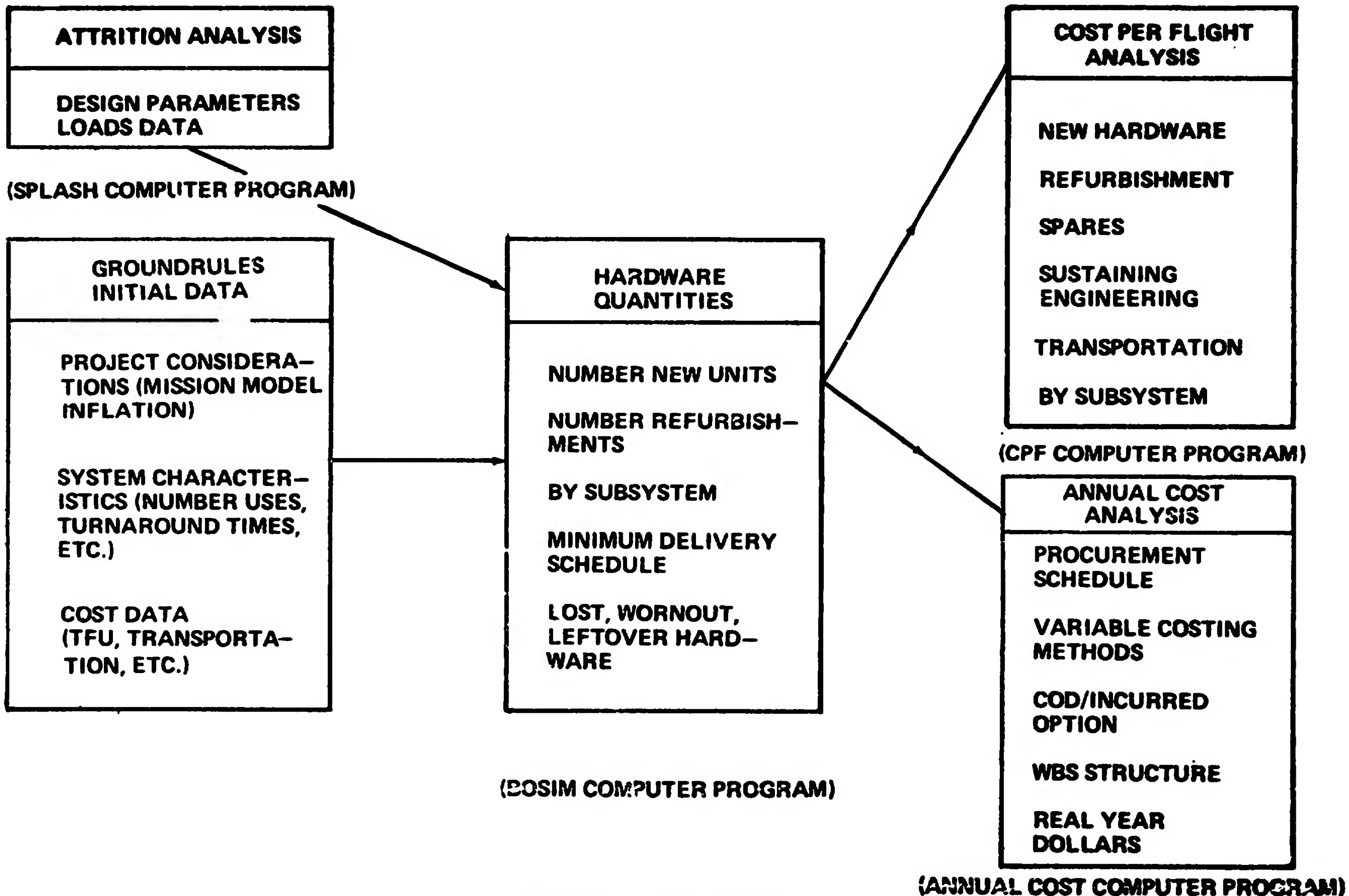


Figure 2. CPF model.

TABLE 1. SRB CPF MODEL COMPUTER PROGRAMS

ATTRITION PROGRAM (SPLASH)

Treats meteorological factors and strength of each SRB element probabilistically to determine loss/ damage (attrition).

LOGISTICS SIMULATION PROGRAM (BOSIM)

Simulates hardware life cycle, i.e., procurement, assembly, launch. recovery, disassembly, refurbishment and subsequent reuse until loss or wearout.

Each unit of each subsystem is serialized and tracked throughout its life.

Currently 53 subsystems identified.

CPF PROGRAM (CPF)

Theoretical First Unit (TFU) cost and learning curve costing method.

TFU's dated and inflated/deflated as required.

ANNUAL COST PROGRAM (ACP)

Hardware delivery schedules considered.

WBS costing format (104 blocks costed).

COD/incurred cost option.

TABLE 2. ATTRITION MODEL (SPLASH)

The SRB attrition model is a Monte Carlo analysis which treats the meteorological factors (wind, sea, etc.) and the strength of each SRB element probabilistically.

Used to determine the probabilistic loss/damage (attrition) of the SRB elements and conduct tradeoffs of design approaches and changes.

Key Features:

> Each critical load condition is programmed as a table of loads input as a function of vertical velocity (V_V), horizontal velocity (V_H) and water impact angle (0).
>
> Present the entire curve instead of the sum of failures (the value of the probability) at a certain strength level.
>
> Can present design limit loads (predicted actual load with no factor of safety) or it can divide the load by a strength ratio probability distribution.
>
> Effect of high altitude wind gusts, low altitude wind gusts, wind shear, parachute release dynamics, and wave slope are all included.
>
> Wave slope is filtered to remove the effect of all waves with wave lengths smaller than the effective length unique for each type of loading.

TABLE 3. LOGISTICS MODEL (BOSIM)

SRB logistics model is a simulation model of the hardware life cycle, i.e., procurement, assembly, launch, recovery, disassembly, refurbishment and subsequent reuse until loss or wearout.

Used to define hardware quantities.

Key Model Features:

- Dual launch sites.
- Hardware shared (if applicable) between launch sites.
- 53 subsystems simulated.
- Each unit of each subsystem is serialized and tracked.
- Sinking test and damage test (treated probabilistically).
- Learning curve for attrition distribution.
- Total turnaround time divided into seven blocks.
- Learning curves considered for refurbishment, assembly, VAB operations and disassembly time.
  - Each site learning curves vary.
- Old/New use philosophy option.
- Limit facility capacity option.

TABLE 4. COST-PER-FLIGHT PROGRAM

CPF program determines the average recurring cost per flight to operate the SRB during DDT&E and operational phase of Shuttle Program. Program Features: CPF elements: New hardware Spares Assembly Refurbishment Sustaining engineering Transportation Other BAC functions DDT&E and operational flights cost split. TFU and learning curve costing method. Spares bought at average unit cost for operational flights new hardware. TFU's dated and inflated/deflated as appropriate. Costs in constant year/quarter dollars. CPF per subsystem computed. Total hardware cost per subsystem computed. Average unit cost per subsystem computed.

TABLE 5. ANNUAL COST PROGRAM

SRB annual cost program determines the real year cost to perform the DDT&E and operational flights for total SRB project.

Program Features:

- Hardware delivery schedules for 53 subsystems input.
- Costing methods
  - TFU + learning curve
  - Constant cost/quarter
  - Constant cost/flight
  - Inflation (for any of above)
- Input cost data in any year/quarter dollar.
- COD or incurred cost option.
- WBS structure for costing.
- Vertical/horizontal WBS summations optional.
- DDT&E/operational real year cost split.
- Minimum required, minimum level, early manufacturing hardware delivery options.
- Total new + spares + refurbishment cost available per subsystem.
- No-inflation option available for comparison with CPF program totals.

Logistics computer models have been developed which simulate the subsystem hardware life cycle, i.e., procurement, assembly, launch, recovery, disassembly, refurbishment and subsequent reuse until loss or wearout. The principal hardware characteristics affecting the quantity of new units required and their delivery schedule are the attrition rate, turnaround time, and design useful life [2]. Currently there are 23 SRB reusable subsystems with unique values for these characteristics. Together with 11 subsystems expended on each flight, a total of 34 subsystems are considered in the hardware logistics flow. By repeated computer simulations of performing the total traffic model, with each simulation having a unique pattern of random hardware loss and wearout, estimates can be made of the average number of new units required to sustain the traffic model. In addition, delivery schedules for the units are obtained.

B. Cost-Per-Flight

The hardware quantity results from the logistics simulation together with such non-hardware costs as transportation, assembly, sustaining engineering, etc., form the basis for a total operational flights cost analysis. The theoretical first unit (TFU) cost and learning curve method is used to cost the new hardware procurement and the refurbishment operations. Other cost analysis techniques such as cost/year or cost/service operation are used to cost the remaining Shuttle program elements which are considered chargeable to SRB operations cost. Dividing the total operations cost in constant year dollars by the appropriate number of flights determines the average recurring SRB CPF which can be compared to the Agency commitment to Congress.

C. Real Year Cost

To evaluate the real year cost to operate the SRB project, it is necessary to determine schedules over the 12-year traffic model for manufacture of new hardware, refurbishment of the used hardware, and for performance of service type operations not directly related to hardware procurement. Anticipated inflation from current dollars to real year dollars is an important element in each real year total dollar requirement. Since cost estimates in the total project data base are obtained in a variety of base year dollars, it is necessary to escalate each subsystem or service cost estimate to the appropriate time of procurement or use. For almost all new hardware procurement, it will be necessary to provide some progress payments to the contractor prior to actual hardware delivery. Therefore, a portion of each real year dollar total goes for partial payment of hardware deliverable at a later date.

D. CPF Model Utilization

The CPF model is used to prepare operations flights cost estimates to support budget estimates and Program Operating Plan (POP) exercises. Sensitivity studies are performed to determine the CPF impact of changing major Space Shuttle program parameters. Typical of the many trade studies performed include: (1) impact of TFU and learning curve on total program cost, (2) impact of hardware use philosophy on minimizing leftover hardware (oldest or newest unit in inventory for the next use), (3) cost effective design changes [spending money in Design, Development, Test, and Engineering (DDT&E) to save more in Operations], (4) effect of refurbishment facility capacity on new hardware requirements, (5) impact of DDT&E hardware loss on operational flights hardware requirements, and (6) variation in total program cost and CPF with traffic model.

E. CPF Model Validation

The logistics simulation model and the production planning and cost analysis computer programs have been through several revisions, but have been basically operational for approximately 3 years. Originally, the entire analysis was performed by hand, and hand checks are frequently made. The programs do not make any decisions which cannot be readily verified by hand. The volume of data involved and the need for quick response analysis precludes complete hand calculations. The programs are prediction tools and are based on data and assumptions which are being continually updated as the Shuttle program becomes more defined.

The logistics model developed to simulate the flow of SRB hardware is a complex representation of the system of hardware procurement, assembly, launch, recovery, disassembly, refurbishment and reuse. An important aspect of developing a simulation model is its validation. The primary purpose of validation is to ensure that the simulator is a correct representation of the system and that recommendations based on simulator results are reliable and accurate. Typical activities in the validation of the SRB hardware flow simulation model have included the following:

1) Determine minimum computer running time as a function of confidence interval on the variable being estimated.

2) Construct test cases with boundary conditions which should produce known results.

3) Determine "internal validity;" i.e., if simulation has a low variance of outputs when replicated with all exogenous inputs held constant.

4) Assess credibility of the model by asking people who know the real system to judge whether the model is reasonable.

The construction of test cases and application of reasonable tests has taken place incessantly. In limiting conditions tests, BOSIM agrees with results known to be accurate virtually by inspection. For example, in terms of new hardware quantities to run the mission model, if one inputs 1-day turnaround time, zero attrition rate and 1000 useful life, BOSIM says two motor cases can run the mission model. For 100 percent attrition input, the model says 974 new units are required to perform 487 operational flights. For 12-year turnaround time, the model says 974 are required. For a value of one for useful life, it says 974 are required. For zero attrition input, the output says no units are lost. As the attrition rate increases, more units are lost and thus more new units are required. As the useful life increases, less new hardware is required. As the turnaround time increases, more new hardware is required. All of this is either right or reasonable.

As an additional check for zero attrition the output is deterministic; i.e., nothing is lost before wearout so serial numbered units can be assigned to each of the 487 flights with the appropriate turnaround times and useful lives known. This was done laboriously by hand and matched the BOSIM output exactly. In verifying the cost calculations, we take advantage of the fact that the CPF program and the ACP program were developed independently by different people from two organizations and run on different computers. There was enough similarity between the two programs so that with a small amount of extra work the programs could be made to perform the same calculation of total program cost in 1975 dollars. For each budget exercise we insist that the results match before our submittal.

II. LOGISTICS SIMULATION

Scheduling new SRB hardware requirements and the blending of refurbished units with new units to meet the traffic model would be a much less complex task were it not for the expected attrition of hardware during use. The probability of recovery of the spent SRB stage is estimated to be as low as 0.5 for the first Shuttle flight. This probability is expected to increase rapidly. However, over the 12-year life of the 500 flight traffic model, the structural loads associated with water impact are estimated to cause irrepairable damage an average of from 3 to 25 percent of the time, depending on the particular subsystem component. The attrition is expected to be random and a new unit is as likely to be lost as an almost wornout unit. These factors present difficulties when trying to determine how many new units are required to perform the traffic model and scheduling their delivery to sustain the launch rate. The key parameters involved in reuse planning will be described together with the simulation computer model (BOSIM) developed to perform the logistics analysis. Figures 3 and 4 present top level schematics of SRB hardware flow.

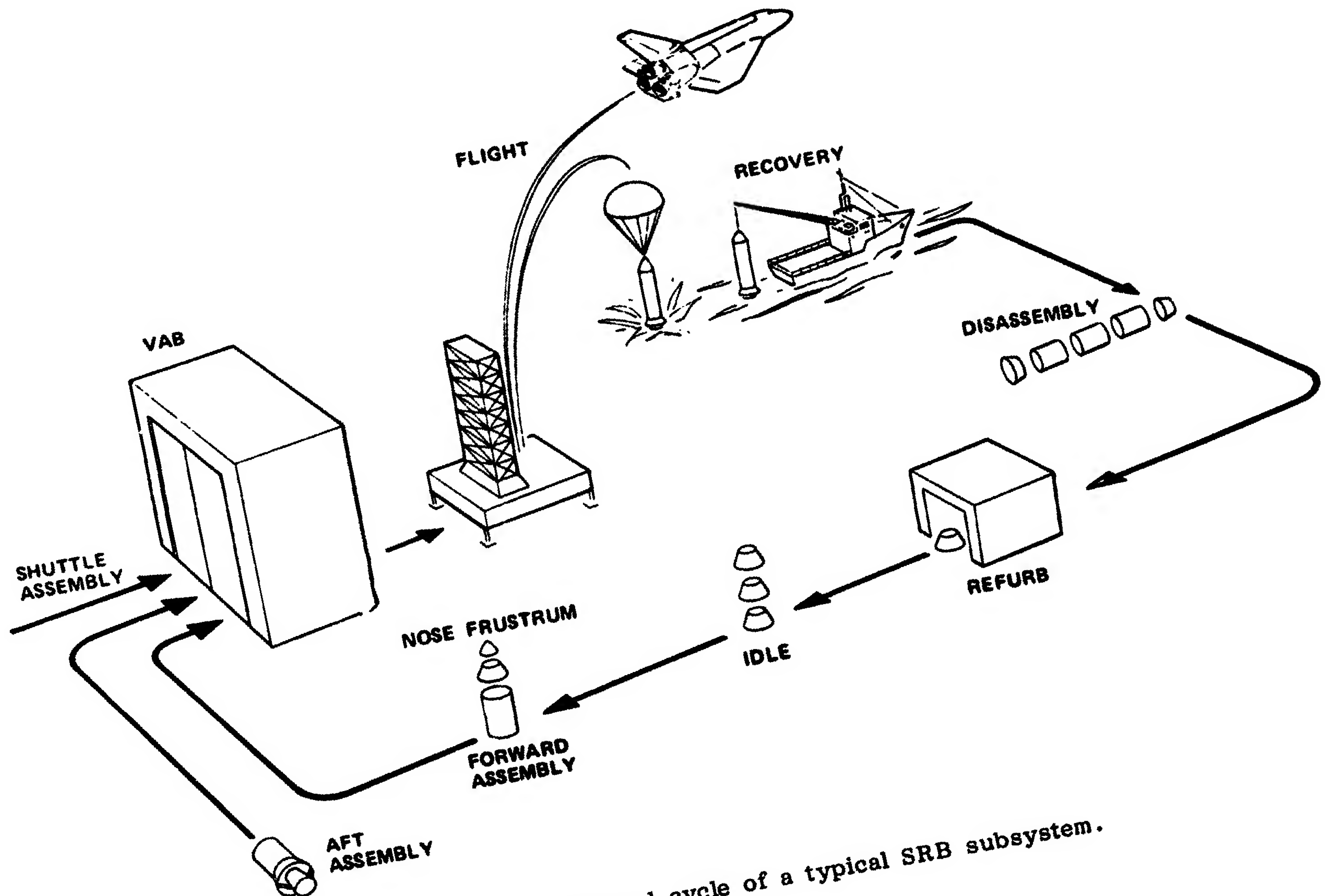


Figure 3. Operational cycle of a typical SRB subsystem.

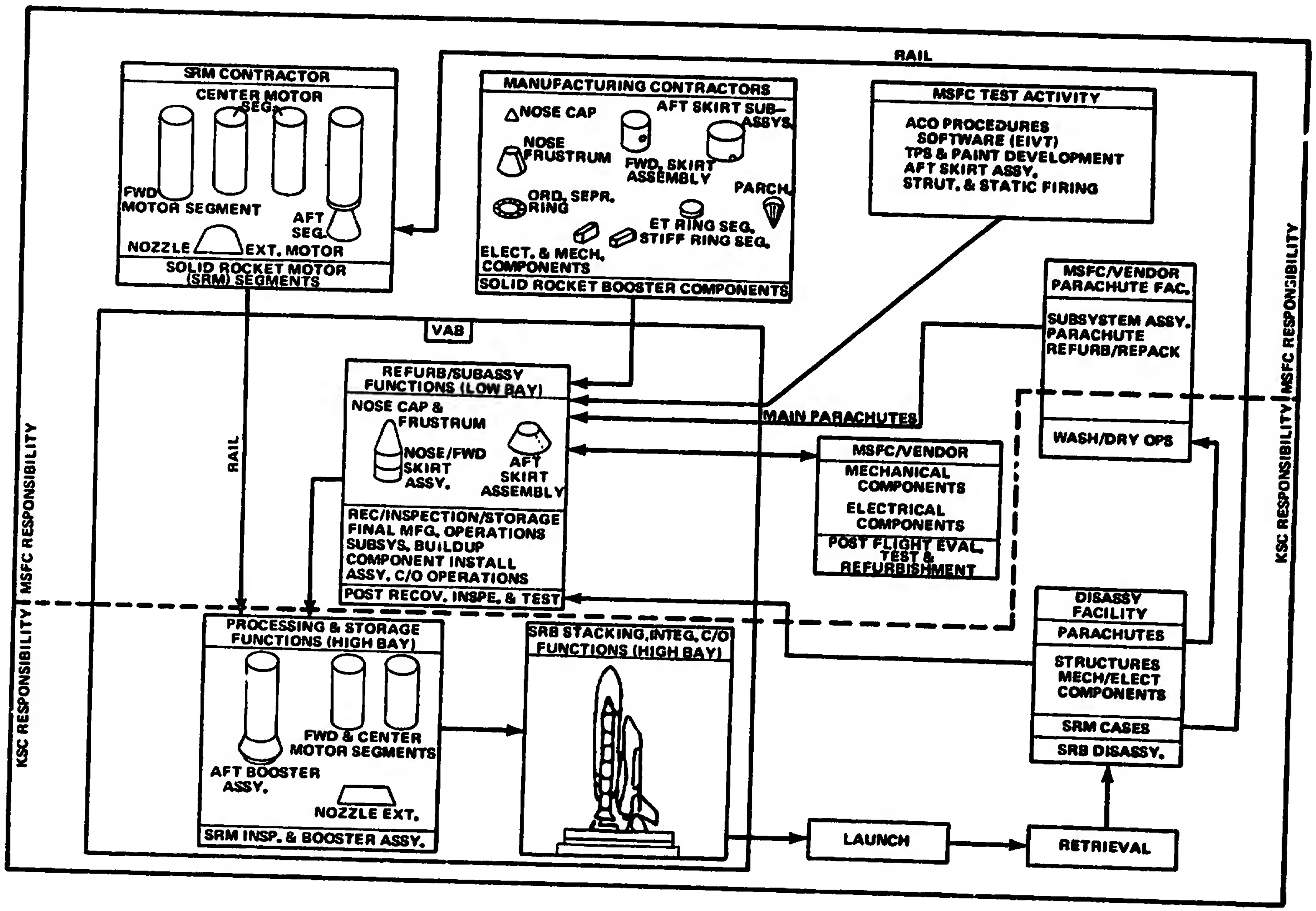


Figure 4. SRB hardware flow.

A. Traffic Model

The traffic model for the space transportation system is defined by NASA Headquarters and is the starting point for a budget estimate and cost-per-flight analysis. Figure 5 is a typical traffic model. The number of launches per fiscal year at the Eastern Test Range (ETR) and Western Test Range (WTR) is shown. Early in the traffic model and particularly for the first six flights, specific launch dates are known (Table 6). The first six flights are referred to as the DDT&E flights and the balance are called operations flights. The logistics simulation model works in days as the basic time unit. In years wh:re only the total number of launches is known at present, launch dates are assigned by equally spacing the launches throughout the year. The computer program which determines launch dates is called MCONVZ and is described in Appendix A. After launch dates are selected, they are treated as fixed as far as the logistics simulation is concerned. New hardware requirements to meet fixed launch dates are desired. It is possible to assume that occasionally a launch would be delayed to utilize a piece of used hardware which is nearing the end of its refurbishment cycle. Doing this could delay the cost of a new piece of hardware if no other used piece is in inventory and immediately available. However, the tradeoffs involved in this type of decision have not been considered; hence, the controlling assumption is that SRB hardware (either new or used) is always available to make a launch on time.

B. Turnaround Time

Turnaround time is defined as the time for a reusable piece of hardware to complete a total reuse cycle. A reuse cycle is broken down into the phases of: launch, retrieval, disassembly, refurbishment, transportation, assembly, stacking, and launch preparation. The time to perform some of these operations is constant; while for others, they are expected to be able to be accomplished in progressively shorter times as experience is gained. A TFU time and learning curve concept is used to predict times to perform the vario··s tasks as the traffic model is flown. Table 7 shows typical times for he aft skirt to proceed through a reuse cycle. After refurbishment a .ɔmp. ·nt may be idle for an unspecified length of time until it is selected for ..n upcoming flight. At that point, it would begin moving through the insulation, assembly, checkout, etc., flow.

C. Hardware Useful Life

Most SRB subsystem components are designed for reuse. The design number of reuses is shown in Table 8. During actual Shuttle operational flights, some hardware will be lost due to attrition before

FY	79				80				81				82				83			
QTR	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
DDT&E				1	1	1	1	2												
OPS									1	2	3	4	2	4	4	5	5	5	5	7
KSC									1	2	3	4	2	4	4	5	5	5	5	5
WTR										-	-	-	-	-	-	-	-	-	-	2
Annual Total	1				5				10				15				22			
FY	84				85				86				87				88			
QTR	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
OPS	8	9	9	10	11	11	12	12	12	13	13	13	12	13	14	13	14	15	15	14
KSC	7	8	7	8	8	8	9	9	9	9	9	9	8	8	9	9	10	10	10	10
WTR	1	1	2	2	3	3	3	4	3	4	4	4	4	5	5	4	4	5	5	4
Annual Total	36				47				51				52				58			
FY	89				90				91				92				Total			
QTR	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
DDT&E																			6	
OPS	12	13	14	14	14	14	15	14	14	14	14	13	13	13	5				487	
KSC	9	9	10	10	10	10	11	10	10	10	9	9	9	9	4				(358)	
WTR	3	4	4	4	4	4	4	4	4	4	5	4	4	4	1				(129)	
Annual Total	53				57				55				31						493	

Notes: The above 487 flights include 27 reflights.
The 439th flight is the tenth flight in third quarter of FY91.
Quarterly flight allocations through FY82 are per option cargo manifest 5/24/78.
2 sites/4 orbiters.

Figure 5. STS traffic model.

TABLE 6. STS TRAFFIC MODEL (487)

78-2 Option (5/24/78), Mission Model 601 POP 78-2,
Launch Dates for Flights 1-32

Flight No.	Launch Date (CY)	Flight No.	Launch Date (CY)
1	08/31/79	17	10/15/81
2	12/31/79	18	11/15/81
3	03/31/80	19	01/10/82
4	06/01/80	20	01/20/82
5	08/01/80	21	03/10/82
6	09/30/80	22	03/20/82
7	12/31/80	23	04/15/82
8	01/15/81	24	05/10/82
9	02/15/81	25	05/20/82
10	04/15/81	26	06/15/82
11	05/15/81	27	07/10/82
12	06/15/81	28	07/20/82
13	07/15/81	29	08/15/82
14	08/15/81	30	09/10/82
15	09/10/81	31	09/20/82
16	09/20/81	32	10/15/82

TABLE 7. AFT SKIRT DDT&E AND INCREMENT II TURNAROUND TIMES IN DAYS

			RSF			KSC OPS				RSF	
			"Assembly" in BOSIM								
	Flight Number	New Hdw. Buildup	Assem.	Insul.	ACO	PSF	Stack, Pad, Launch	Retrev.	Disasm.	Refurb.	Total Turnaround*
DDT&E	1	67 day	–	34	45	23	88.2	7	24	20	241.2
	2	TFU @	–	31.6	41.9	21.4	54.9	7	22.3	17.8	196.9
	3	93% Learn	–	30.3	40.1	20.5	41.7	7	21.4	16.9	177.9
	4	for only	–	29.4	38.9	19.9	34.2	7	20.8	16.3	166.5
	5	those	–	28.7	38.0	19.4	29.4	7	20.3	15.9	158.7
	6	flights	–	28.2	37.3	19.1	26.0	7	19.9	15.6	153.1
Increment 2 OPS	7	where	–	27.7	36.7	18.8	22.8	7	19.6	15.3	147.9
	8	new units	–	27.3	36.2	18.5	22.5	7	19.3	15.1	145.9
	9	are	–	27.0	35.8	18.3	22.2	7	19.1	14.9	144.3
	10	required.	–	26.7	35.4	18.1	22.0	7	18.9	14.7	142.8
	11		–	26.5	35.0	17.9	21.8	7	18.7	14.5	141.4
	12		–	26.2	34.7	17.7	21.6	7	18.5	14.4	140.1
	13		–	26.0	34.4	17.6	21.4	7	18.3	14.3	139.0
	14		–	25.8	34.1	17.4	21.2	7	18.2	14.2	137.9
	15		–	25.6	33.9	17.3	21.1	7	18.1	14.1	137.1
	16		–	25.4	33.7	17.2	20.9	7	18.0	14.0	136.2
	17		–	25.3	33.4	17.1	20.8	7	17.8	13.9	135.3
	18		–	25.1	33.2	17.0	20.7	7	17.7	13.8	134.5
	19		–	25.0	33.1	16.9	20.6	7	17.6	13.7	133.9
	20		–	24.8	32.9	16.8	20.5	7	17.5	13.6	133.1

*Less new hardware buildup time

RSF – Refurbishment Subassembly Facility
KSC – Kennedy Space Center
OPS – Operations
PSF – Processing Storage Facility
ACO – Assembly Checkout

TABLE 8. SRB USEFUL LIFE

Subsystem / Component	Useful Life Design	Useful Life Average
SRM		
Aft Cylinder	20	10
Fwd Cylinder	20	8
Aft Stiff Tees	40	8
Other Segments		
Cylinder	20	12
Fwd Closure	20	12
Attach (ET)	20	11
Aft Closure	20	9
Joint Hdwe, Pins	20	14
Nozzle		
Snubber	20	4
Elastomer	10	1
Bearing Shims	20	11
Aft End Ring	20	5
Fwd End Ring	20	7
Compliance Ring	20	5
Other Parts	20	7
Igniter	20	13
Propellant	1	1
Insulation and Liner	1	1
E&I		
E&I (DFI)	1	1
E&I (OFI)		
Fwd Skirt Components	20	14
IEA's	20	14
Recovery Battery	1	1
Altitude Switch	20	11
Frustum Loc. Aid (FLA)	20	5
FLA Battery	1	1
Reusable Fwd. Cables	20	14
Reusable Aft Cables	20	13
Expendable Cables	1	1
Sensors	20	13
TVC		
Actuator	20	6
Power Supply	20	6

TABLE 8. (Concluded)

Subsystem	Useful Life	
Component	Design	Average
Structures		
Nose Cap	1	1
Nose Frustum	40	10
Separation Ring	1	1
Fwd Skirt	40	15
Systems Tunnel		
Fwd	40	17
Aft	40	14
ET Attach Ring	40	17
SRB/ET Attach Struts		
Reusable	40	19
Expendable	1	1
Aft Skirt	40	5
Thermal Shield	1	1
Recovery		
Pilot Chute	1	1
Drogue Chute	10	7
Main Chute	10	7
Main Chute Support Structure	40	10
Satellite Floats (Pinger for Early Flights)	20	12
Separation Motors	1	1
Pyrotechnics	1	1
Range Safety		
Electronic Equipment	20	14
Battery	1	1

reaching its design useful life. In addition, irregularities in the traffic model and refurbishment cycle preclude perfect scheduling of component reuse. Thus, at the end of the traffic model there will be left-over hardware. All these inefficiencies contribute to hardware being used less than its design number of uses. In Table 8 the column "Average" gives the actual number of uses, on the average, achieved from each component. For purposes of the CPF model, the SRB is broken down into the components shown in Table 8.

D. Attrition

Attrition of SRB subsystems is generally considered to be broken down into two categories: (1) general attrition, which is attrition from causes independent of SRB design characteristics, and (2) design attrition, which is attrition that is a function of design characteristics, such as strength. Examples of the first category are losses from accidents during transportation, launch operations, and retrieval. Examples of the latter category are losses due to excessive parachute deployment loads and excessive water impact loads. Losses during initial manufacturing are not included in attrition as these costs are assumed in new hardware costs. The sum of the general and design attrition is defined as average total program attrition for the duration of the mission model. Typical attrition values are presented in Table 9.

The probability of losing a piece of hardware is likely to decrease as experience is gained during the mission model. There are undoubtedly unidentified sources of attrition, errors in prediction of water impact loads or conditions, and errors in prediction of capability that could increase the attrition rates. As these are discovered, options are available to counteract these increased attrition sources. Changes in design of the parachute subsystem will reduce the water impact velocity, changes in design of the structure will increase capability, and changes in operational procedures will reduce the attrition during recovery. Attrition will then tend to start out higher than predicted and improve as design changes are implemented, following a step improvement or a learning curve improvement during the program.

E. Spares

Spares in the classic DOD sense of replacements for any failed component is not considered in the logistics simulation. We adopt the philosophy that, due to the probabilistic nature of determining new hardware quantities, additional new units above the mean value should be purchased to increase confidence that enough new hardware is available to make all launches on time. Spares in this sense are defined as the additional hardware required for a 95 percent probability of meeting the traffic model. Any hardware required to replace piece part random failures not related to attrition-producing mission loads are called "logistics spares" and are costed as additional hardware in the CPF model. Numerous simulations suggest that four units extra (above the mean new units required) will, on the average, give a 95 percent confidence of having enough hardware to meet all launches on time. The question of when the hardware is delivered also bears on the issue of confidence in meeting launches and will be discussed later.

TABLE 9. SRB ATTRITION RATES (ETR)

Subsystem	Component	Attrition Percentage		
		Design	General	Total
SRB				
	Aft Cylinder	2.60	3.70	6.20
	Fwd Cylinder	4.90	3.70	8.42
	Aft Stiff Tees	1.70	3.70	5.34
	Other Segments			
	Cylinder	0.00	3.70	3.70
	Fwd Closure	0.00	3.70	3.70
	Attach (ET)	0.00	3.70	3.70
	Aft Closure	1.32	3.70	4.97
	Joint Hardware, Pins	0.00	3.70	3.70
	Nozzle			
	Snubber	19.70	3.70	22.67
	Elastomer	78.20	3.70	79.01
	Bearing Shims	0.15	3.70	3.84
	Aft End Ring	12.40	3.70	15.64
	Fwd End Ring	7.00	3.70	10.44
	Compliance Ring	15.30	3.70	18.43
	Other Parts	7.00	3.70	10.44
	Igniter	0.00	3.70	3.70
	Propellant	0.00	100.16	100.16
	Insulation and Liner	0.00	100.16	100.16
E&I				
	E&I (DFI)	0.00	0.00	0.00
	E&I (OFI)			
	Fwd Skirt Components	0.00	3.59	3.59
	IEA's	0.00	3.59	3.59
	Recovery Battery	0.00	100.15	100.15
	Altitude Switch	0.60	4.92	5.49
	Frustum Loc. Aid (FLA)	14.43	4.92	18.64
	FLA Battery	0.00	100.15	100.15
	Reusable Fwd. Cables	0.20	3.59	3.78
	Reusable Aft Cables	0.60	3.59	4.17
	Expendable Cables	0.00	100.15	100.15
	Sensors	0.60	3.59	3.78
TVC				
	Actuator	11.70	3.59	14.87
	Power Supply	9.11	3.59	12.37

TABLE 9. (Concluded)

Subsystem / Component	Attrition Percentage Design	General	Total
Structures			
Nose Cap	0.00	100.15	100.15
Nose Frustum	0.50	4.92	5.40
Separation Ring	0.00	100.15	100.15
Fwd Skirt	0.10	3.59	3.69
Systems Tunnel			
Fwd	0.60	3.59	4.20
Aft	1.80	3.59	5.30
ET Attach Ring	0.00	3.59	3.59
SRB/ET Attach Struts			
Reusable	0.00	3.59	3.59
Expendable	0.00	100.15	100.15
Aft Skirt	15.54	3.59	18.57
Thermal Shield	0.00	100.15	100.15
Recovery			
Pilot Chute	100.00	0.68	100.68
Drogue Chute	4.02	4.21	8.06
Main Chute	6.67	1.38	7.96
Main Chute Support Struct.	0.50	4.92	5.40
Satellite Floats (Pinger for Early Flights)	0.00	4.92	4.92
Separation Motors	0.00	100.15	100.15
Pyrotechnics	0.00	100.15	100.15
Range Safety			
Electronic Equipment	0.00	3.59	3.59
Battery	0.00	100.15	100.15

F. Hardware Use Philosophy

When selecting hardware to build up the assemblies for the next flight during operational flights, new units, refurbished units with few uses, or refurbished units with many accumulated uses may be available for use. For the purposes of this discussion, "use philosophy" means the methods used to determine when new hardware copies are introduced, where new copies are introduced [Eastern Test Range (ETR) or Western Test Range (WTR)], and which of several available new or refurbished copies will be employed on each Shuttle launch. Some examples of possible use philosophies are as follows:

1) Use a refurbished unit if available and a new unit only if no refurbished units are available.

2) When the choice is among several refurbished units, select the one with the most accumulated uses.

3) When several refurbished units are available, select the one with fewest uses.

4) Select a new unit if available, even if refurbished units are available.

An ideal use policy would have the following features: (1) the total dollars spent for hardware acquisition, storage, refurbishment, and use would be minimized; (2) the risk of having an inadequate or excessive inventory at any time would be low; and (3) the dollars spent in the "early years" would be near minimum. No precise definition of "early years" has been made. Unfortunately, a policy which satisfies one of these objectives usually aggravates the problem of satisfying another. For example, the best way to minimize total dollars spent (ignoring inflation) is to buy just enough hardware to meet launch requirements, buy it early enough, switch to a "newest first" policy early enough so that wearouts and leftover uses are minimized, and buy it late enough to minimize the impact of storage costs. Such a policy (if it can be implemented) will probably not minimize "early year" funding. The relative values of the three objectives are difficult to assess.

Some simulations of the operational cycles of the reusable SRB subsystems have shown that the quantities of hardware required can be significantly affected by the use philosophy. The original work [4] was limited to one SRB subsystem, the Solid Rocket Motor Middle Segments or "Other Segments." The Middle Segments subsystem was shared between the ETR and WTR; that is, a copy used at one site for one launch could, after refurbishment, be used at the other site on a subsequent launch. With shared subsystems, there was no need to specify where new copies would be introduced; therefore, the problem of assigning new copies to a launch site was eliminated. It was found [4] that some plans for putting middle segments into use earlier than absolutely necessary could produce a more even distribution of uses on the copies, which prevented wearouts and reduced the total copies required. One objective is to determine what characteristics make possible reductions from the established quantities of new units. In the following paragraphs, some use philosophy terms are defined and the results of study to date are discussed.

When SRB subsystem units have finished refurbishment and are available for reassembly into another SRB for another launch; they are said to be in an "available pool" until they are physically committed to assembly. Until then, it is possible to substitute a different unit without perturbing the normal assembly and prelaunch sequence. Consequently, a choice between units having different numbers of accumulated uses is

sometimes possible. If new units are delivered as late as possible, the content of the available pool is minimized. Then little difference is evident between a policy of choosing the oldest available unit versus the policy of choosing the newest available unit.

The situation changes when early delivery of units occurs. Early delivery means delivery earlier than the latest possible time to achieve on-time launches. With early delivery, the size of the available pool is large enough so that it is not frequently totally depleted. A policy of using the oldest available unit first causes some new units to sit idle while the first used units accumulate uses. If the mission model contains enough launches, the first used units tend to wear out at the earliest possible time. Early delivery has no effect on the total number of units required if a policy of using the oldest available unit first is employed.

Early delivery with a policy of using the newest available unit first can sometimes reduce the total units required. It is not necessary to use the newest first policy through the entire mission model to obtain reductions. What is necessary is that the newest first policy be adopted early enough to permit equalization of accumulated uses before wearouts occur.

The longer the SRB subsystem's turnaround time, the earlier the policy of using the newest first must be adopted to achieve use equalization. This is true because more units are required in the use-refurb loop when the subsystem has a long turnaround time. More units in the loop means more launches must be processed to get a response to policy changes. It is relatively easy to get as close to full utilization as the mission model and attrition allow when the turnaround time is short. (Full utilization means uses obtained are equal to the designed maximum for the subsystem.)

The combination of early delivery of units and switching from using the oldest available first to the newest available first produces a situation where savings or disaster can occur. Savings in the quantity of hardware occurs if just enough hardware is bought to complete the mission model with all the leftover units being almost worn out. Disaster is possible if the wrong number is bought early causing many to wear out shortly before the mission model is completed. The replacement units then inflate the total new units required, and many almost new units are leftover. Most of the SRB subsystem units will be bought early simply because uniform production rates and few startups are required to get reasonable unit costs.

Significant changes in the quantities of the long turnaround subsystems can be brought about by variations in delivery timing and available pool manipulation since these affect the degree of utilization (uses obtained compared to designed maximum) of the units. Before reasonable delivery schedules can be defined, constraints on manufacturing rates, startup times, and budgets need further definition. Some kind of tradeoff will have to be made between the desire to minimize

early year funding and the desire to keep total program cost near minimum. The relative values of these goals must be established. More detailed discussion and example calculations of these concepts are contained in References 4 and 5.

G. System Simulation

A "simulation"[1] model (called BOSIM for Booster Simulation) is used to determine the quantity of new components needed to perform the traffic model. BOSIM also determines when those new components must be delivered to make all launches on schedule. Figure 4 depicts the hardware flow simulated. Figure 6 simplifies the hardware flow and the highlighted blocks are analogous to the facilities and events modeled by BOSIM. Going an additional step and introducing some simulation language terminology, Figure 7 depicts the physical system of SRB use. A more detailed flow chart and program description is presented in Appendix B. BOSIM is documented in References 6 through 9.

To understand what BOSIM does, it is best to begin by considering how one might determine by hand the number of aft skirts needed to perform the traffic model. Figure 8 presents an example. Across the top of the figure are the year, month, day of the month for each launch and launch number. Down the left-hand column are the serialized new aft skirts. The two questions we now ask ourselves are (1) which aft skirts are assigned to which flights and (2) when must new aft skirts be introduced to sustain the launch rate. A new aft skirt is delivered to the launch site on the latest date such that it can begin preassembly activities (|). Following that is assembly/stacking (▽), then launch (▼), then completion of refurbishment (X), followed by storage (···). The first 6 flights (DDT&E) are covered by special groundrules. Two aft skirts are required for each flight. Aft skirts 1/2, 3/4, 5/6, 7/8, 9/10 are assigned to Flights 1, 2, 3, 4 and 5. Flight 6 will use aft skirts 3/4 from Flight 2. Flights 7 and subsequent present choices for aft skirt assignments. Let us adopt the hardware use philosophy that the oldest available aft skirts (lowest serial numbers) will be used first and new aft skirts (beyond the ten used on the first 6 flights) will not be introduced unless necessary to make a launch on time. For Flight 7 on May 30, 1980, we therefore select serial numbers 1 and 2. They begin assembly/stacking on April 23, 1980. For Flight 8 on July 1, 1980, numbers 1 and 2 are in refurbishment and hence not available. Numbers 3 and 4 are idle on the launch date, having come out of refurbishment

1. Simulation is the process of designing a model of a real system and conducting experiments with the model for the purpose of understanding the behavior of the system and of evaluating various strategies for the operation of the system.

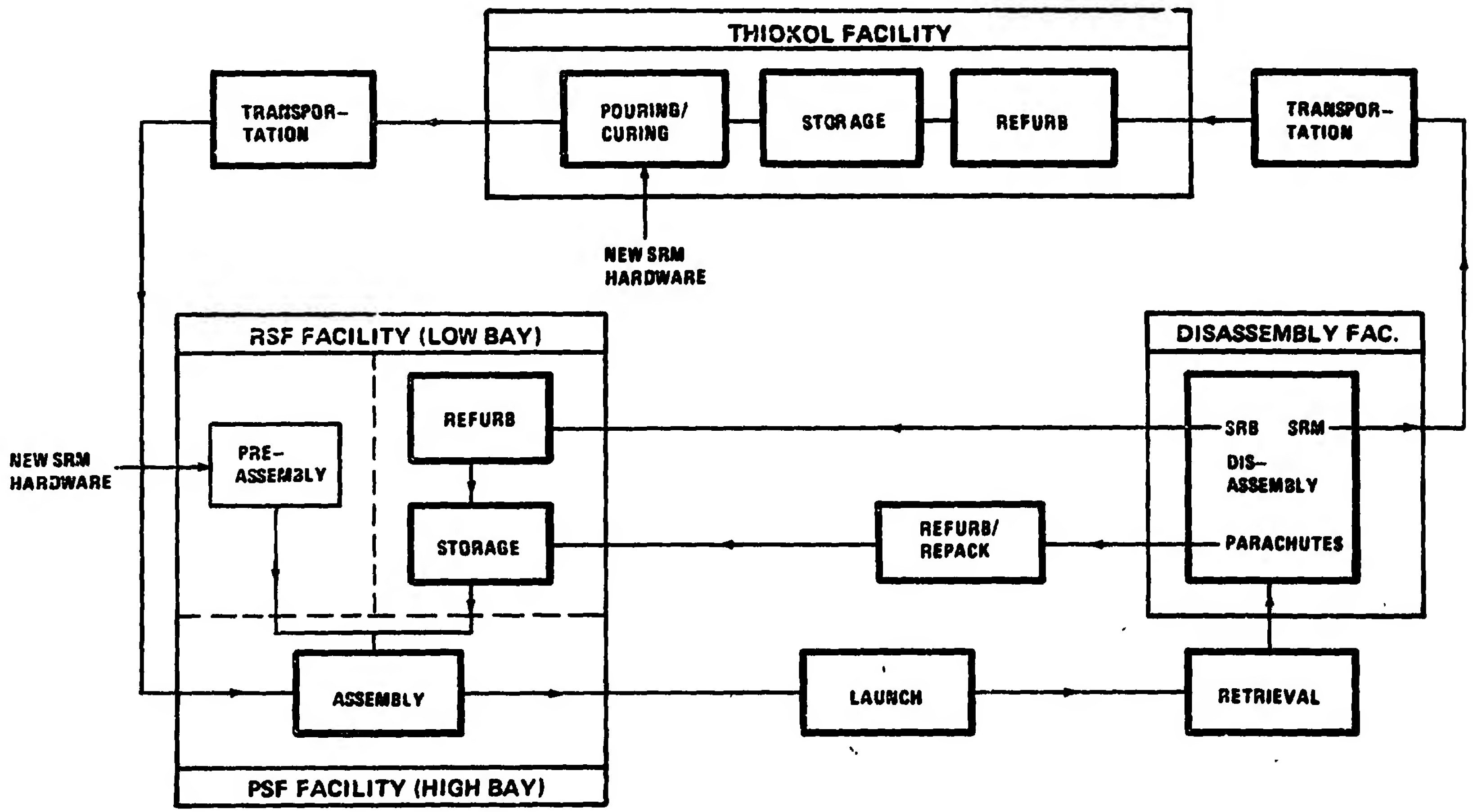


Figure 6. Top-level BOSIM flowchart.

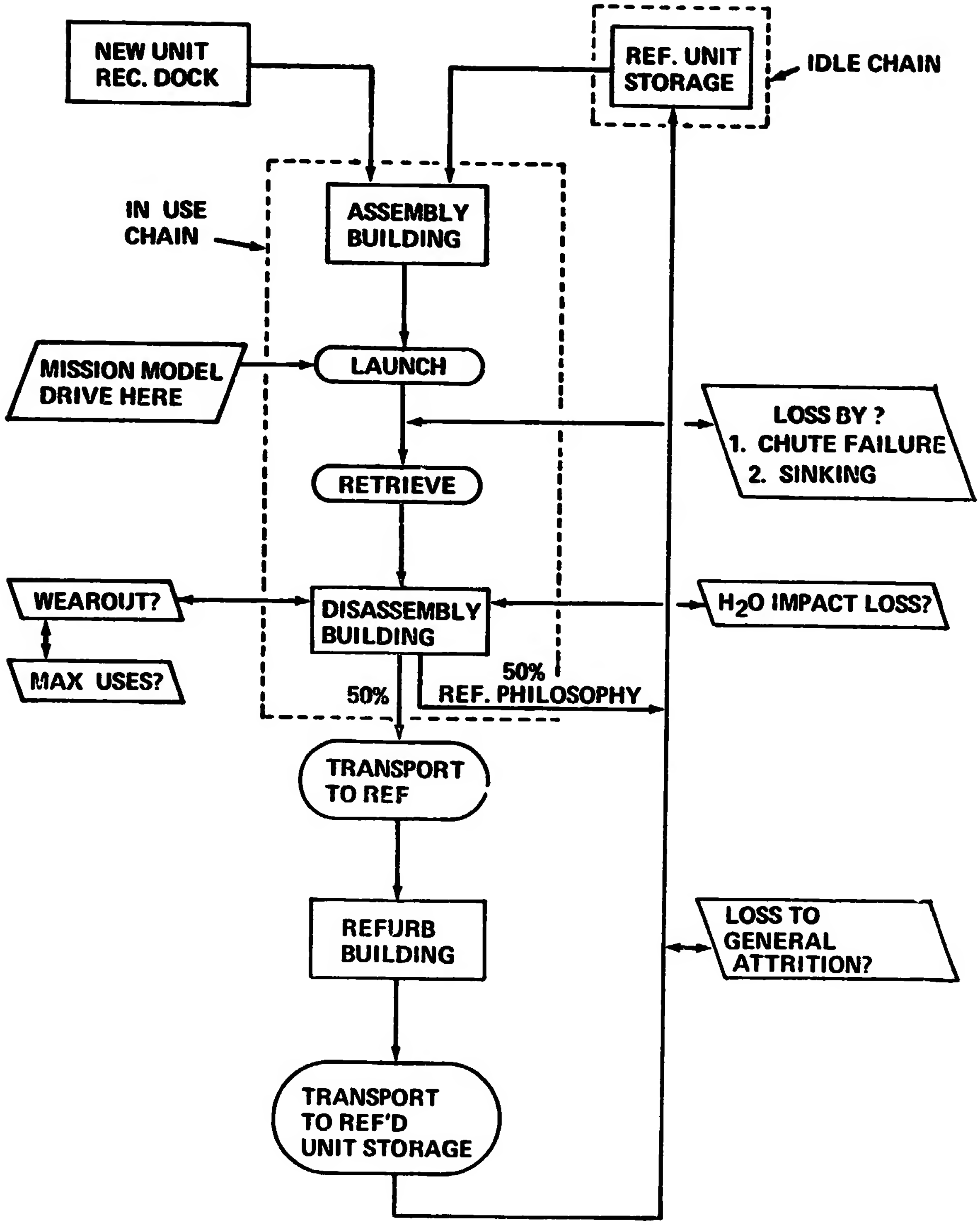


Figure 7. Physical system for SRB use.

on June 6. However, they needed to have been available on May 24 when assembly/stacking must begin for Flight 8. Hence, we assign numbers 5 and 6 to Flight 8. The pattern should now be clear. For each launch date, one simply backs up 37 days, looks at the status of all aft skirts as of that date, and selects the lowest serial numbered pair and assigns them to that launch date.

There will come a time when, due to the launch frequency increasing, all 10 original aft skirts will be tied up in some point in their turnaround cycle. Such occurs on Flight 25, January 5, 1982. It is now necessary to introduce new aft skirts numbered 11 and 12 to sustain the launch rate. We have neglected attrition and the hardware planning can be called deterministic.

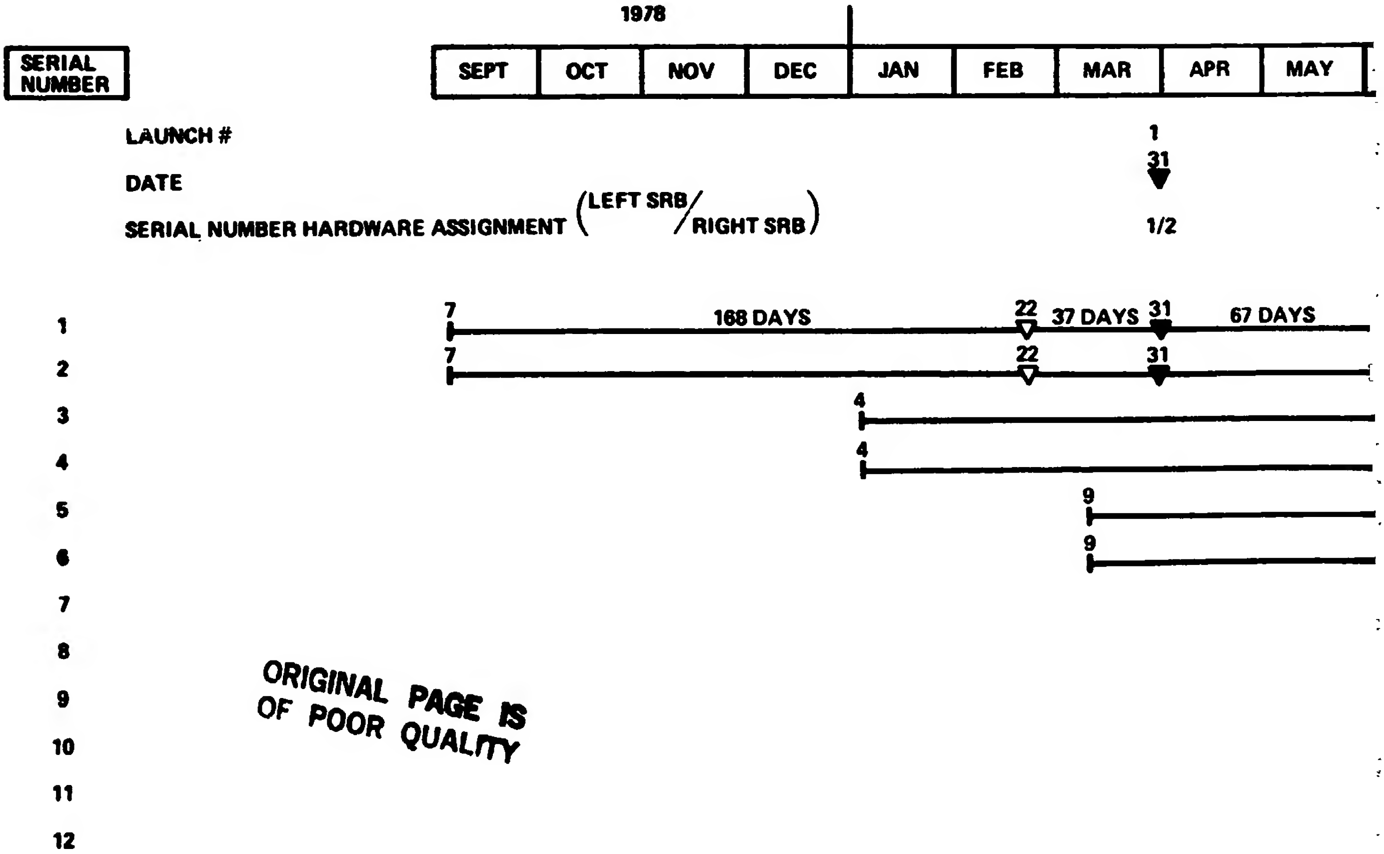
We now consider the realistic case in which an aft skirt may be lost or irrepairably damaged during any use. Figure 9 depicts this situation. Figure 9 is constructed the same as Figure 8 except for one change. Immediately following each launch, a 12 percent chance was taken that each aft skirt was lost. If it was lost then it was removed from the system and is no longer available for reuse. The first aft skirt to be lost was number 5 on Flight 8. Number 4 was lost on Flight 11. A dramatic change in the number of new aft skirts needed is evident when attrition is considered. In Figure 8, ten aft skirts ran 24 flights while in Figure 9 sixteen were required to run 24 flights.

It is very important to understand that the pattern of losses in Figure 9 is one of many possible loss patterns and each has different implications in terms of the number of new aft skirts needed to run the launch schedule and when those new aft skirts must be delivered to make launches on time. In simplest terms, BOSIM runs an experimental launch schedule and lets each aft skirt take a chance of being lost on each use. Each pattern of losses, as the launch schedule progresses, has its own unique consequences in terms of new aft skirt quantities required and associated delivery dates. By averaging the results of hundreds of simulations, the mean number of new aft skirts required is determined. This is called probabilistic hardware planning. Other SRB subsystems subject to attrition are treated similarly.

Because of the relatively small number of simulations per sample with BOSIM, the question arises whether the change in sample mean from case to case is a result of random variations to be expected from a limited number of simulations per sample or is a result of a change in population mean due to an input data change. The possibility also exists that a change in input data will not affect the population mean. Analytical procedures have been developed to evaluate the significance of a change in sample mean to attribute that change to a variation in population mean or to a random variation due to small sample size [3].

▮ INITIAL DELIVERY TO LAUNCH SITE FOR PRE–ASSEMBLY ACTIVITIES
▽ BEGIN ASSEMBLY/STACKING
▼ LAUNCH
X COMPLETION OF REFURBISHMENT
······· STORAGE

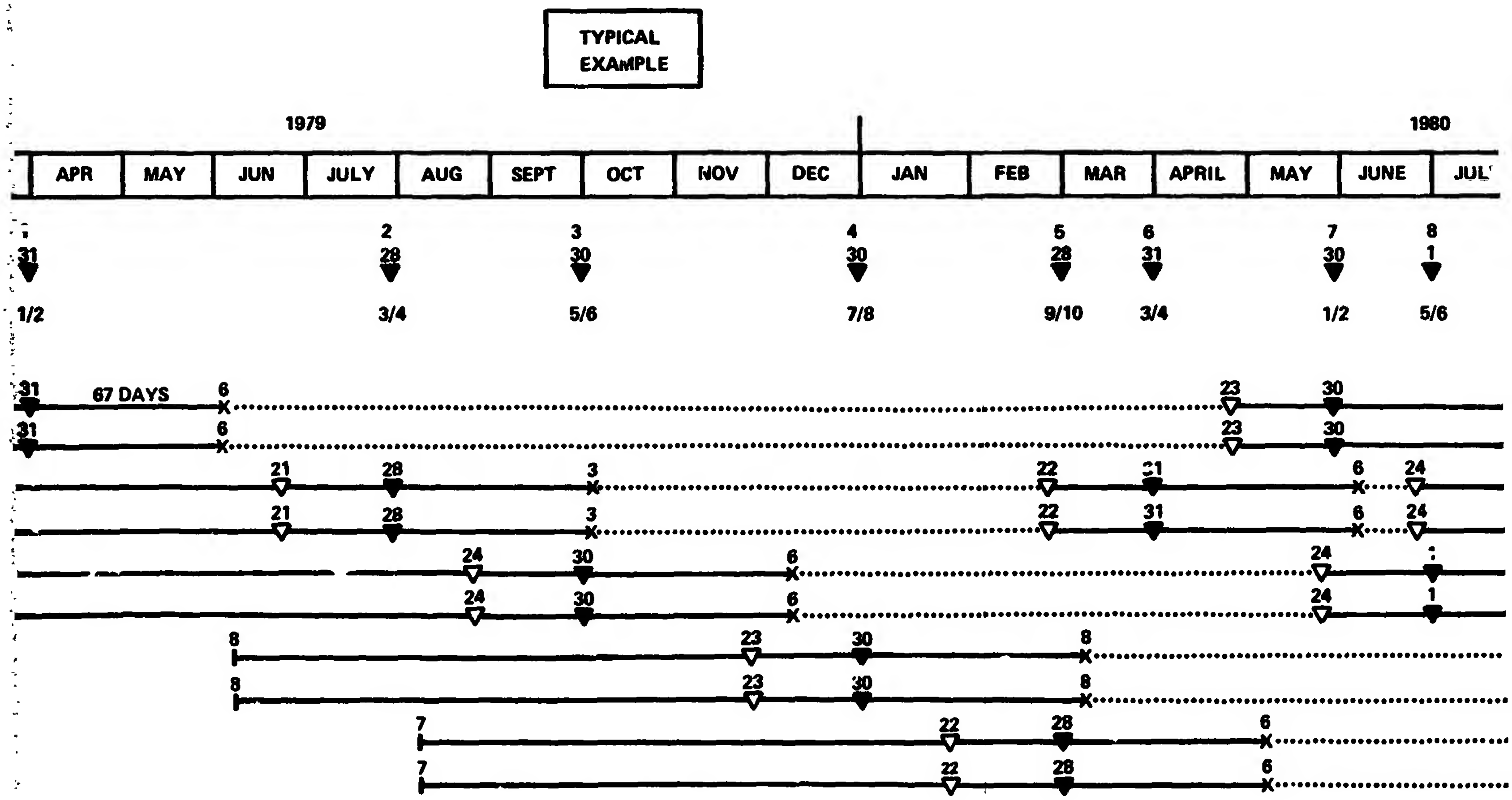
CHART 1



GROUNDRULES:

NEW HARDWARE ASSIGNED TO FIRST 5 DDT&E FLIGHTS, 6TH FLIGHT USES REFURBISHED 2ND FLIGHT HARDWARE.
BEGINNING WITH 7TH FLIGHT USE OLDEST HARDWARE FIRST.
ASSUME CONSTANT TIMES FOR TURN AROUND EVENTS: PRE–ASSEMBLY 168 DAYS; LAUNCH ASSEMBLY/STACKING
DISASSEMBLY/REFURBISHMENT 67 DAYS
AFTER 6TH FLIGHT, NEW HARDWARE INTRODUCED ONLY IF NECESSARY TO MEET MISSION MODEL.
ATTRITION RATE ASSUMED ZERO%.
USEFUL LIFE – 40 USES TO WEAR OUT.
NUMBERS IN THE BODY OF THE CHART ARE DATES IN THE MONTH.

AFT SKIRT



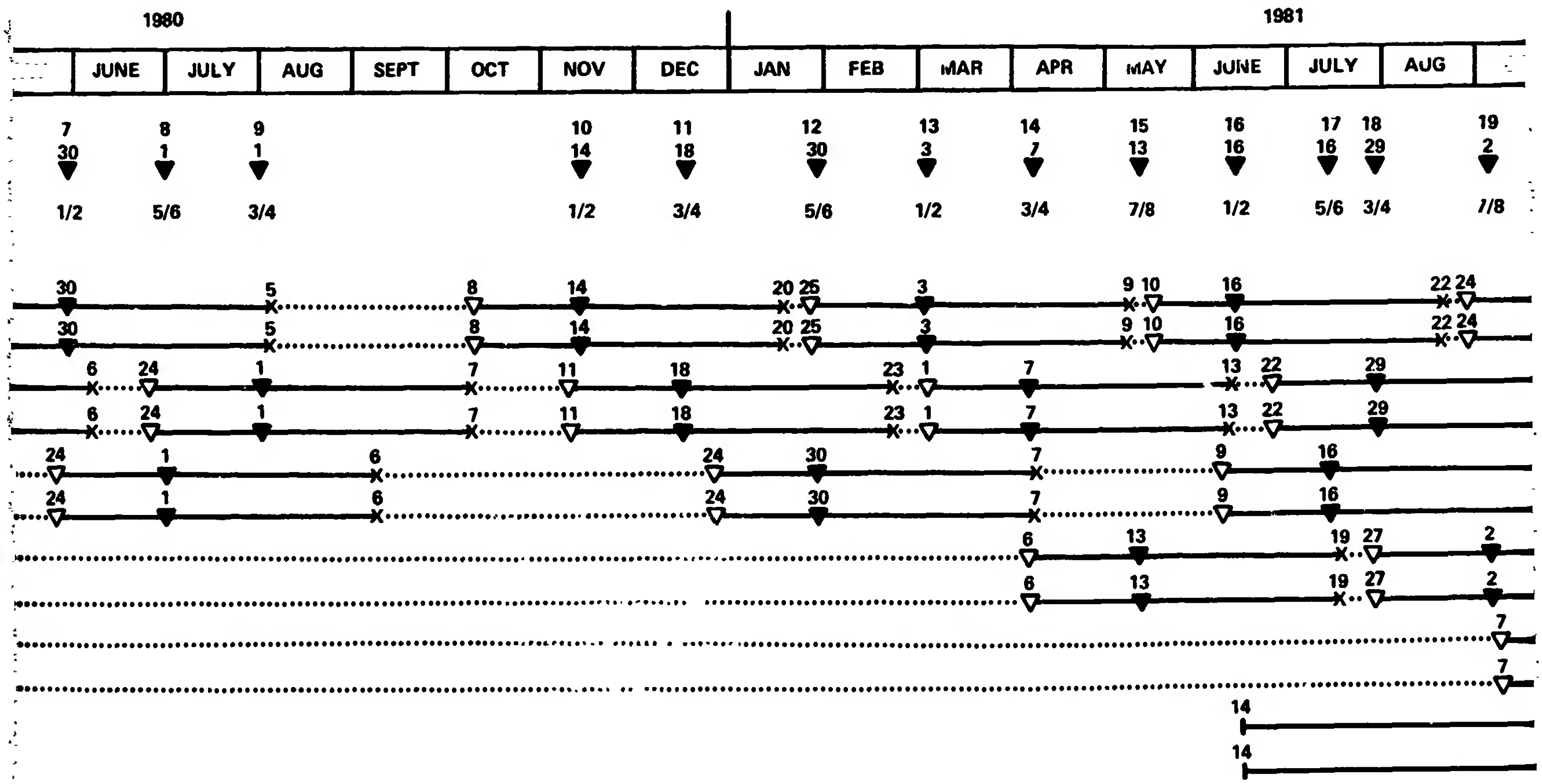
LIGHT HARDWARE.

SEMBLY/STACKING 37 DAYS;

IEL.

FOLDOUT FRAME 2

AFT SKIRT HARDWARE FLOW



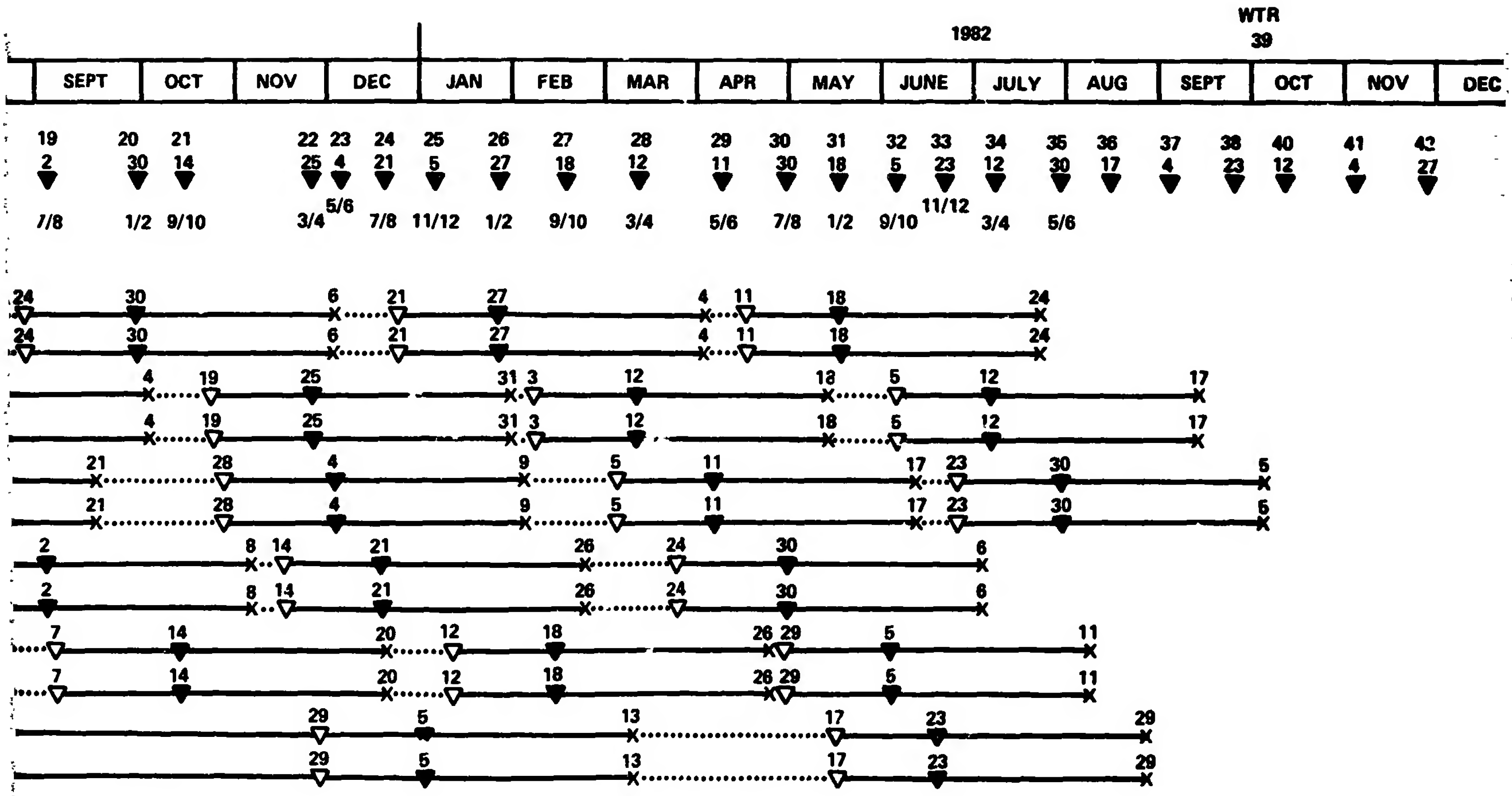
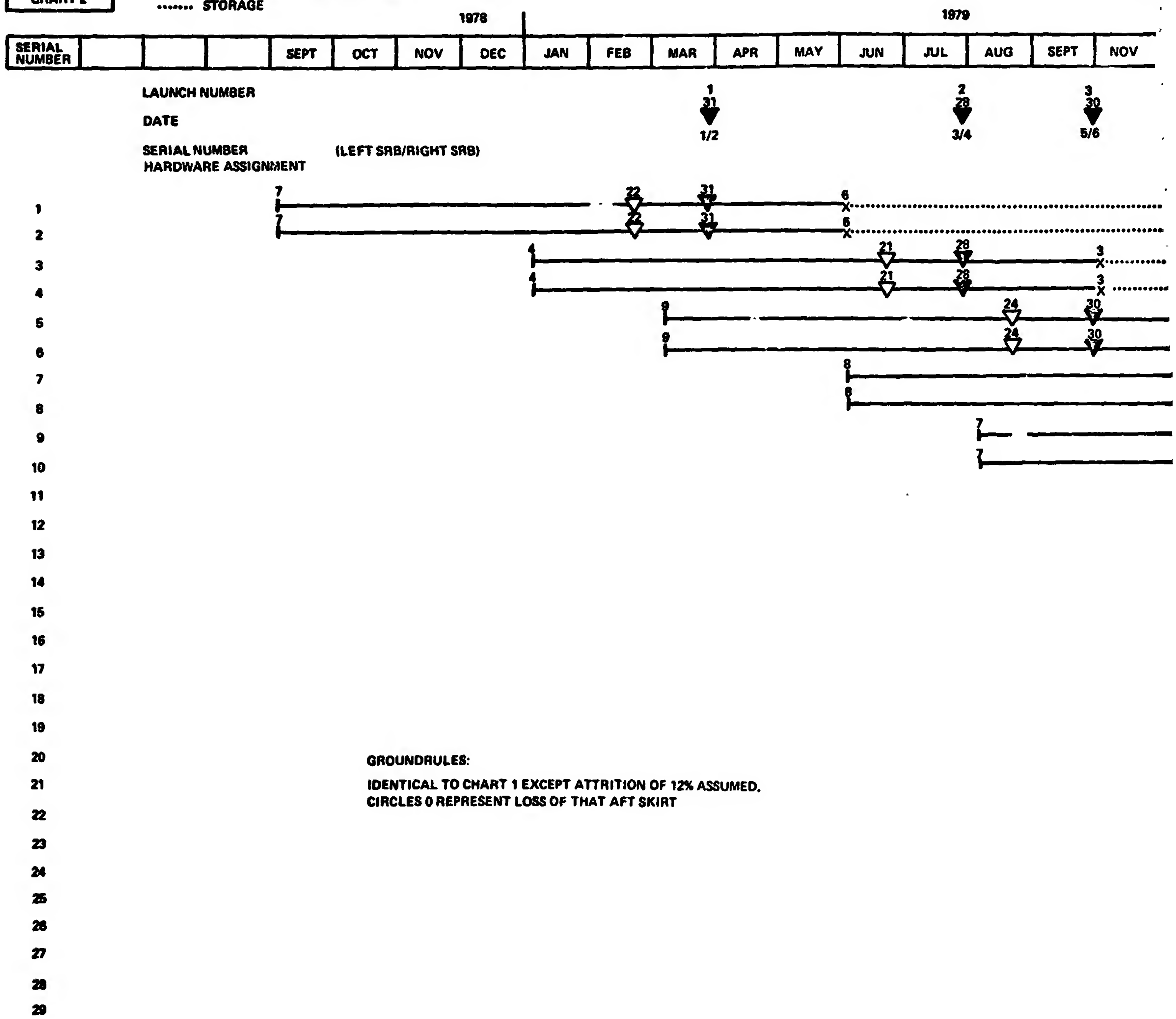


Figure 8. Aft skirt hardware flow (Chart 1).

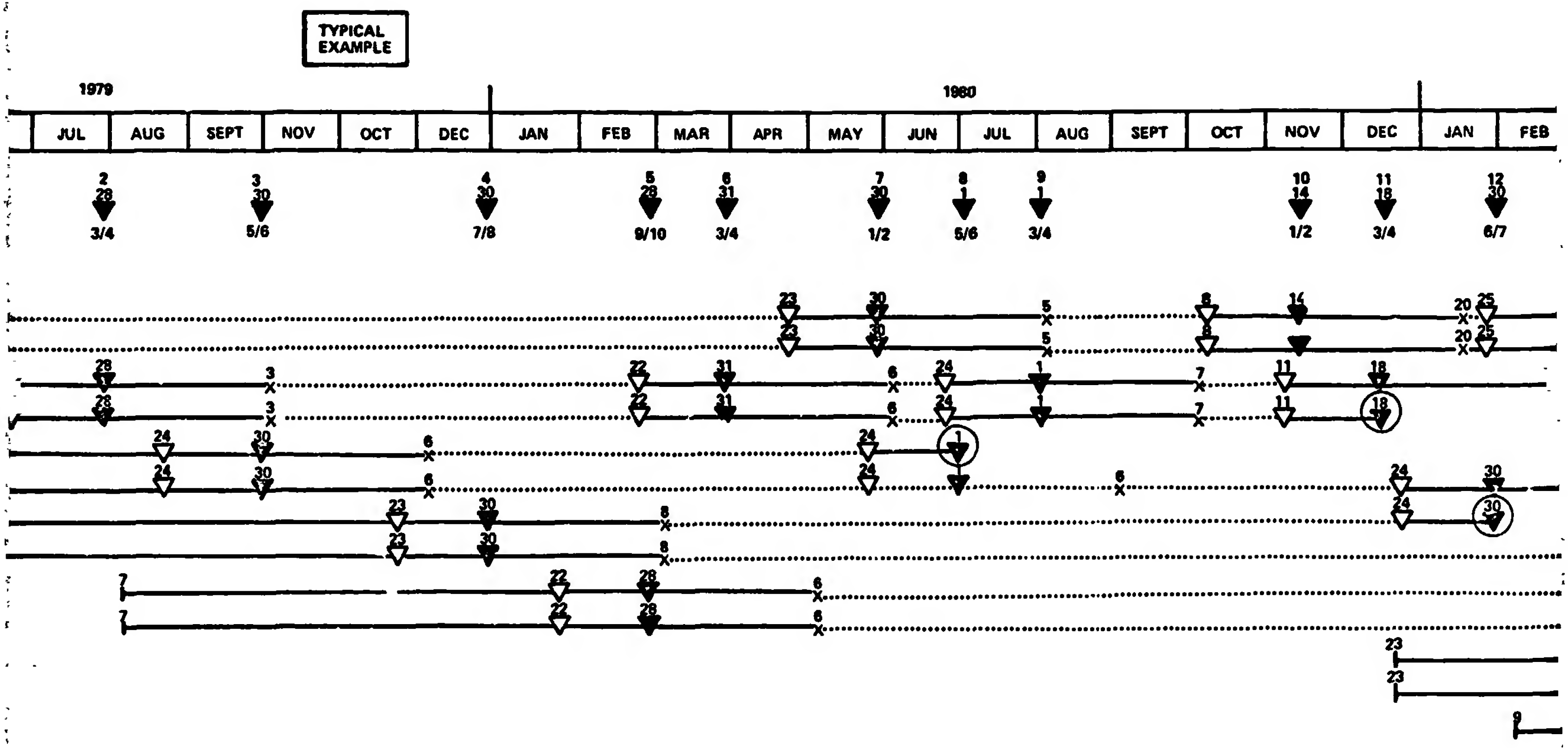
OLDOUT FRAME 3

CHART 2

INITIAL DELIVERY TO LAUNCH SITE FOR PRE–ASSEMBLY ACTIVITIES
BEGIN LAUNCH ASSEMBLY/STOCKING
LAUNCH
X COMPLETION OF REFURBISHMENT
.... STORAGE



FOLDOUT FRAME



FOLDOUT FRAME 2

AFT SKIRT HARDWARE FLOW

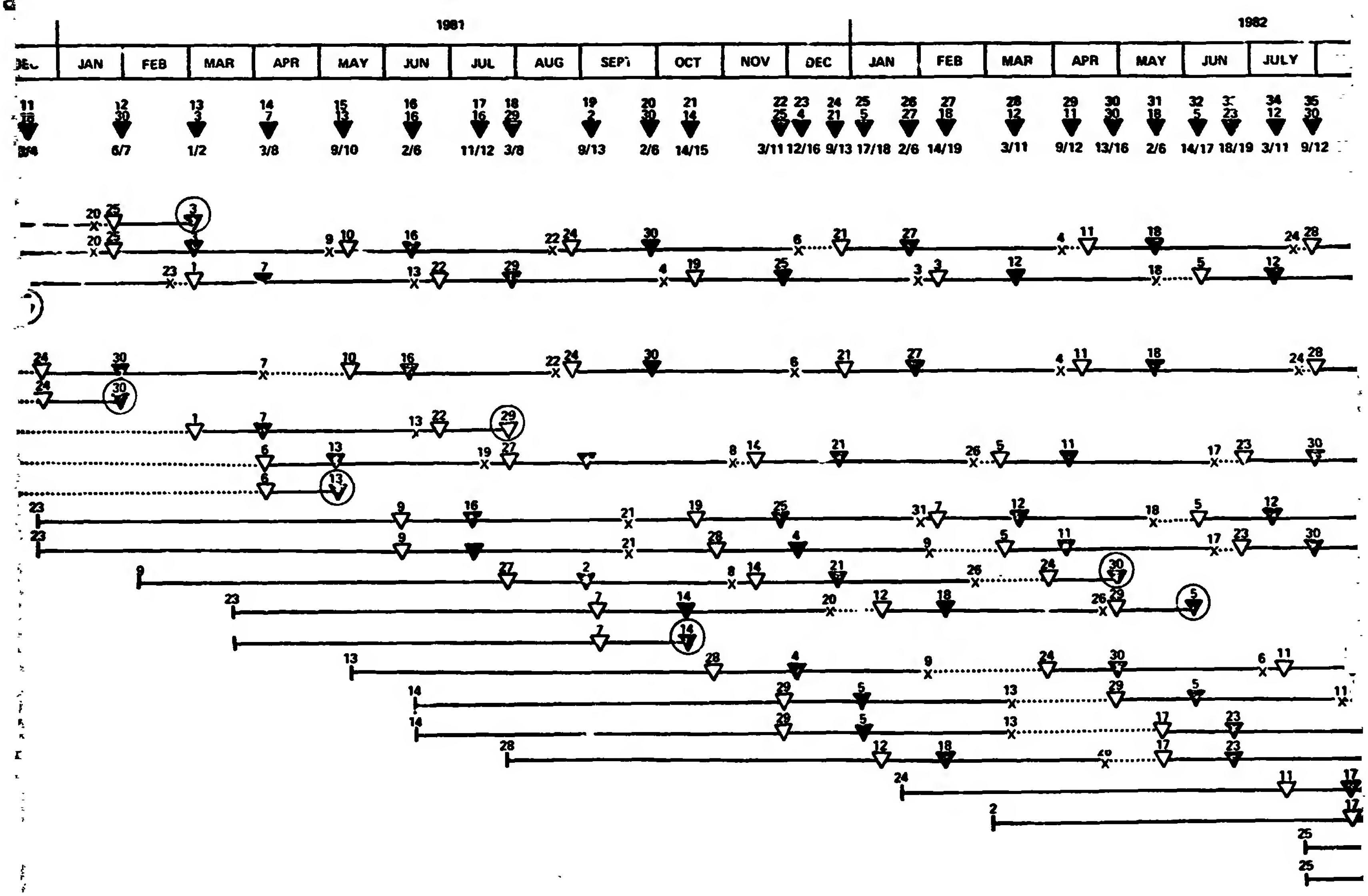
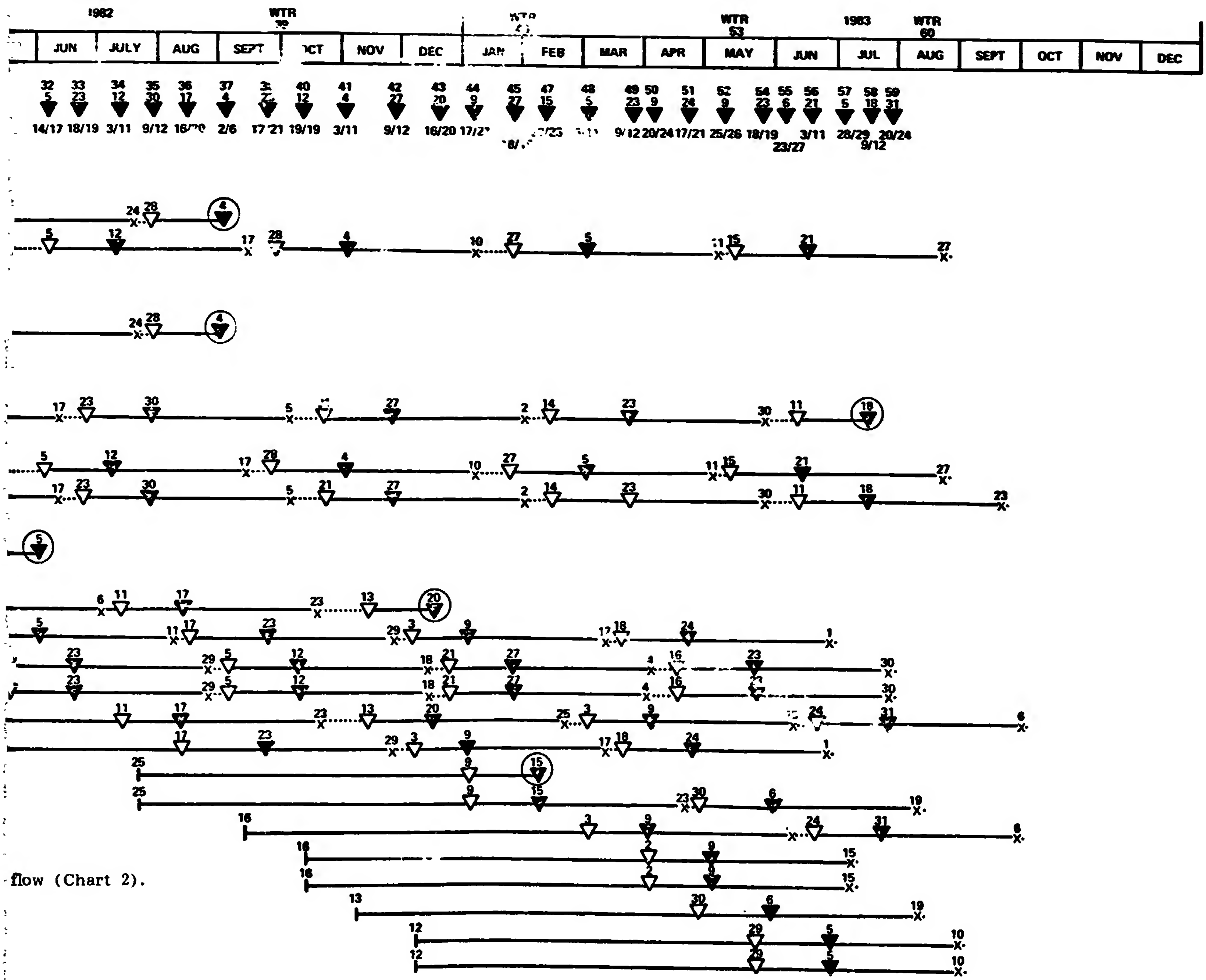


Figure 9. Aft skirt hardware flow (Chart 2).

FOLDOUT FRAME 3



flow (Chart 2).

FOLDOUT FRAME

H. Simulation Results

A feature of BOSIM is that hardware components are serialized and tracked throughout their life cycle. Their location in the turnaround cycle is known. Thus facility occupancy data are available. Averages of key BOSIM output parameters over many replications give logistics data such as: quantities and need dates of new components, refurbishment schedules, location and quantity of units at specific points, and projected schedules of hardware loss and wearout.

The basic printout of BOSIM data is shown in Figure 10. The number of new, lost, wornout and leftover aft skirts is shown for ETR, WTR, and the total of both. For this computer run, 25 cases or replications were used to define the population mean. The standard deviations are also shown. The date format is such that the answer for FY 79/1st Quarter is shown in the upper left hand corner of the data group. One of the key pieces of data is labeled "Highest cumulative total per quarter for all replications." This means, for example, that as of FY 83/1 there was one replication out of the 25 that had required 23 new aft skirts and, further, no other replication had required more. Note that the mean requirement at this same time is 16.08. Refurbishment and disassembly queue output means the number of units waiting to be processed in the refurbishment and disassembly facilities. In this particular example the facilities were considered to have unlimited capacity, hence a queue of zero content developed. The word "available" is synonymous with idle or in storage; i.e., this is the number of units which have been refurbished and are available for flight assignment. The last page of Figure 10 shows new aft skirts required on a per flight basis rather than a quarterly basis. This example shows that 10 new aft skirts are required on Flights 1 to 5. These 10 aft skirts perform the traffic model up to Flight 14 where one more is required. Again on Flights 22 and 25, new aft skirts must be introduced. Also shown are the new hardware requirements through certain flights in the total traffic model and the mean uses left on the hardware available at the end of the traffic model.

A new aft skirt, and all subsystems to some extent, must go through a new hardware buildup activity between the time it first arrives on-dock at the launch site until it is ready to be included in the launch assembly flow the first time it is used. Figure 11 is an example of how the assignment of new aft skirts to particular flights is translated into delivery quarters; i.e., when the new aft skirt is "required" to be on-dock at the launch site to begin processing to make its first launch use on time.

BOSIM results for various mission models are presented in References 10, 11, and 12. A study of range safety system hardware requirements is presented in Reference 13. Refurbishment schedules have been an important BOSIM area of study. References 14, 15, and 16 present results for various components and groundrules.

AVERAGES FOR 25 CASES

	NEW	LOST	WORNOUT	LEFT
ETR	93.76	86.52	.16	7.08
WTR	39.24	32.48	.00	6.76
BOTH	133.00	119.00	.16	13.84

STANDARD DEVIATIONS FOR 25 CASES

	NEW	LOST	WORNOUT	LEFT
ETR	8.32	[illegible].66	.37	1.47
WTR	4.55	4.62	.00	1.13
BOTH	[illegible].77	1[illegible].[illegible]	.37	1.9[illegible]

Format for dates on following pages:

FY:	79/1	79/2	79/3	79/4	I	80/1	80/2	80/3	80/4	I	etc. ...
	83/1	83/2	83/3	83/4	I	84/1	84/2	84/3	84/4	I	etc. ...
	87/1	87/2	87/3	87/4	I	88/1	88/2	88/3	88/4	I	etc. ...
	91/1	91/2	91/3	91/4	I	92/1	92/2	92/3	92/4	I	

Total By Year:

1979 1980 1981 ... 1992

Figure 10. Typical printout for aft skirt.

AFT SKIRT

```
NEW UNITS DELIVERED      AFTSKR

MEAN RUNNING TOTAL ETR + WTR
   .00     .00     .00    2.00  I   4.00    6.00    8.00   10.00  I  10.00   10.00   10.00   10.84  I  10.92   11.12   13.40   14.20  I
 16.08   16.96   19.72   23.36  I  27.04   29.12   31.28   34.88  I  38.76   41.20   44.44   48.76  I  50.56   54.08   57.24   60.52  I
 67.84   67.88   70.88   74.00  I  78.36   82.72   86.68   89.48  I  91.08   94.28   98.40  101.56  I 104.84  108.04  112.00  115.00  I
117.80  121.40  123.88  127.40  I 130.32  132.96  133.00  133.00  I
STANDARD DEVIATIONS
   .00     .00     .00     .00  I    .00     .00     .00     .00  I    .00     .00     .00    1.34  I   1.35    1.54    2.04    2.45  I
  2.57    3.39    3.36    3.88  I   3.71    3.81    4.52    4.89  I   5.20    5.11    5.20    5.58  I   5.53    6.56    7.01    8.06  I
  7.56    7.99    7.92    8.46  I   8.75    8.44    8.98    9.07  I   9.46    9.32    9.61    9.59  I   9.36    9.15    9.96    9.23  I
  7.55    9.67    9.17    9.40  I   9.29    9.70    9.77    9.77  I
MEAN NEW UNITS DELIVERED      AFTSKR

AT ETR BY QUARTER
   .00     .00     .00    2.00  I   2.00    2.00    2.00    2.00  I    .00     .00     .00     .84  I    .09     .20    2.28     .40  I
  1.76     .88     .76    1.64  I   3.68    1.72    1.28    2.96  I   1.76    1.44    2.44    1.64  I   1.64    1.84    2.24    2.32  I
  1.88    1.88    2.00    2.40  I   3.24    2.24    2.36    2.36  I   1.60    2.04    3.40    2.32  I   2.64    2.36    2.92    2.08  I
  1.92    2.16    1.60    2.52  I   1.76    1.72     .04     .00  I
AT WTR BY QUARTER
   .00     .00     .00     .00  I    .00     .00     .00     .00  I    .00     .00     .00     .00  I    .00     .00     .00     .30  I
   .00     .00    2.00    2.00  I    .00     .36     .88     .64  I   2.12    1.00     .80    2.68  I    .16    1.68     .92     .96  I
  1.44    2.16    1.00     .72  I   1.12    2.12    1.60     .44  I    .00    1.16     .72     .84  I    .64     .84    1.04     .92  I
   .48    1.44     .88    1.00  I   1.16     .92     .00     .00  I
TOTAL BY QUARTER
   .00     .00     .00    2.00  I   2.00    2.00    2.00    2.00  I    .00     .00     .00     .84  I    .08     .20    2.28     .80  I
  1.76     .88    2.76    3.64  I   3.68    2.08    2.16    3.60  I   3.88    2.44    3.24    4.32  I   1.80    3.52    3.16    3.28  I
  3.32    4.04    3.00    3.12  I   4.36    4.36    3.96    2.80  I   1.60    3.20    4.12    3.16  I   3.28    3.20    3.96    3.00  I
  2.40    3.60    2.48    3.52  I   2.92    2.64     .04     .00  I
ROUNDED UP TOTAL BY QUARTER
     0       0       0       2  I      2       2       2       2  I      0       0       0       1  I      0       1       2       1  I
     2       0       3       4  I      4       2       2       3  I      4       3       3       4  I      2       4       3       3  I
     3       4       3       3  I      5       4       4       3  I      2       3       4       3  I      3       4       3       3  I
     3       4       2       4  I      3       2       0       0  I
TOTAL BY YEAR
  2.00    8.00     .84    3.36    9.16   11.52   13.88   11.76   13.48   15.48   12.08   13.44   12.40    5.60

HIGHEST CUM TOTAL PER QTR FOR ALL REPLICATIONS      AFTSKR

TOTAL BY QUARTER
     0       0       0       2  I      4       6       8      10  I     10      10      10      14  I     14      15      18      19  I
    23      24      27      31  I     35      36      40      44  I     48      50      53      59  I     60      65      68      73  I
    78      82      86      91  I     96     100     104     104  I    108     109     112     116  I    123     122     126     128  I
   131     136     138     143  I    144     148     149     149  I

MEAN UNITS LOST      AFTSKR
```

Figure 10. (Continued).

```
AT ETR BY QUARTER
   .00    .00    .00    .12  I   .00    .00    .36    .16  I   .32    .68    .44   1.16  I   .48    .76   1.08   1.28  I
  1.88    .76   1.12    .96  I  1.96   2.12   1.60   2.00  I  1.64   1.44   1.00   1.80  I  1.88   2.04   2.24   2.44  I
  1.83   1.92   2.08   2.04  I  2.28   2.28   2.36   2.48  I  2.44   2.12   2.00   2.92  I  2.28   2.16   2.76   2.36  I
  2.60   2.20   2.28   2.44  I  1.92   2.20   1.32    .00  I

AT WTR BY QUARTER
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .28  I   .36    .32    .52    .76  I   .64   1.04    .68    .92  I   .64    .96   1.16   1.12  I
  1.00   1.20   1.56   1.08  I  1.04   1.60   1.60    .84  I   .72    .68    .80    .68  I   .84   1.04    .96    .76  I
   .98   1.16   1.08   1.32  I   .92    .84    .44    .00  I

TOTAL BY QUARTER
   .00    .00    .00    .12  I   .00    .00    .36    .16  I   .32    .64    .44   1.16  I   .48    .76   1.08   1.28  I
  1.88    .76   1.12   1.24  I  2.32   2.44   2.12   3.56  I  2.28   2.48   2.48   2.72  I  2.56   3.00   3.40   3.56  I
  2.40   3.12   3.64   3.12  I  3.32   3.88   3.96   3.32  I  3.16   2.80   2.80   3.60  I  3.12   3.20   3.72   3.12  I
  3.48   3.36   3.36   3.76  I  2.84   3.04   1.76    .00  I
TOTAL BY YEAR
   .12    .52   2.56   3.60   5.00  10.44   9.96  12.52  12.68  14.48  12.36  13.16  13.96   7.64

MEAN BURNOUT UNITS      AFTSKR

AT LTR BY QUARTER
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .08    .04  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .04    .00  I

AT WTR BY QUARTER
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .00    .00  I

TOTAL BY QUARTER
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .08    .04  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .00  I   .00    .00    .04    .00  I
TOTAL BY YEAR
   .00    .00    .00    .00    .00    .00    .00    .00    .12    .00    .00    .00    .00    .04

MEAN REFURBS COMPLETED      AFTSKR

AT LTR BY QUARTER
   .00    .00    .00    .00  I   .92   1.12    .96   2.44  I   .76   1.76   1.60   2.80  I  3.12   2.44   3.76   2.96  I
  4.40   4.04   4.68   4.72  I  5.00   6.80   7.64   7.60  I  6.68   6.48   8.32   7.72  I  7.28   8.32   8.00   7.68  I
  1.15   7.16   6.44   7.76  I  9.72   8.36   8.68   9.36  I  8.40   7.48   8.72   8.84  I  8.52   8.40  10.04   9.16  I
  8.32   9.12   8.80   8.76  I  7.84   7.32   4.64    .84  I

AT WTR BY QUARTER
   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I   .00    .00    .00    .00  I
   .00    .00    .00    .84  I  1.40    .48   1.36   1.60  I  2.88   2.76   2.48   2.76  I  3.68   3.04   3.40   3.36  I
  3.24   1.86   4.28   3.84  I  3.40   3.68   4.44   3.48  I  3.44   2.72   3.80   3.68  I  3.60   2.96   3.32   3.44  I
```

Figure 10. (Continued).

```
  3.52    3.00    4.28    3.28  I    3.88    3.48    2.84     .00  I

TOTAL BY QUARTER
   .00     .00     .00     .00  I     .92    1.12     .96    2.44  I     .76    1.76    1.60    2.80  I    3.12    2.44    3.76    2.96  I
  4.40    4.04    4.68    5.56  I    6.40    7.28    9.00    9.20  I    9.76    9.24   10.80   10.48  I   10.96   11.36   11.40   11.04  I
 11.40   11.04   10.72   11.60  I   13.12   12.04   13.12   12.84  I   11.84   10.20   12.52   12.52  I   12.72   11.36   13.36   12.60  I
 11.84   12.12   13.08   12.04  I   11.72   10.80    7.48     .84  I

NOU CLD UP TOTAL BY QUARTER
     0       0       0       0  I       1       2       0       3  I       1       1       2       3  I       3       2       4       3  I
     5       4       4       6  I       6       7       9      10  I       9      10      10      11  I      11      11      12      11  I
    11      11      11      11  I      14      12      13      13  I      11      11      12      13  I      12      11      14      12  I
    12      12      13      12  I      12      11       7       1  I
TOTAL BY YEAR
   .00    5.44    6.92   12.28   18.68   31.88   40.28   44.76   44.76   51.12   47.08   49.44   49.08   30.84

MEAN REFURB CONTENT AT ETR OR UTAH      AFTSKR

      AFT SKIRT
   .00     .00     .00     .10  I     .30     .47     .55     .81  I     .29     .92     .71     .98  I    1.17     .64    1.47    1.18  I
  1.51    1.58    1.45    1.41  I    1.69    1.37    1.13    1.17  I    1.11    1.16    1.24    1.20  I    1.11    1.32    1.24    1.17  I
  1.12    1.08    1.05    1.19  I    1.39    1.22    1.28    1.37  I    1.14    1.20    1.22    1.26  I    1.23    1.20    1.40    1.32  I
  1.22    1.26    1.24    1.11  I    1.10    1.02     .62     .11  I

MEAN REFURB QUEUE AT ETR OR UTAH      AFTSKR

      AFT SKIRT
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I

MEAN ETR REFURB CONTENT      AFTSKR

      AFT SKIRT
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .28  I     .39     .29     .30     .50  I     .78     .82     .73     .96  I     .90    1.04    1.01     .95  I
   .84    1.10    1.24    1.13  I     .93    1.04    1.27    1.06  I     .76     .94    1.08     .99  I    1.03     .82     .91    1.00  I
   .93     .86    1.08    1.04  I    1.03     .95     .60     .00  I

MEAN ETR REFURB QUEUE      AFTSKR

      AFT SKIRT
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I     .00     .00     .00     .00  I
   .00     .00     .00     .00  I     .00     .00     .00     .00  I

MEAN EAST DISASSEMBLY CONTENT      AFTSKR

      AFT SKIRT
```

Figure 10. (Continued).

.00	.00	.00	.34	I	.00	.33	.62	.29	I	.29	.87	.80	.96	I	.62	.96	1.08	1.09	I
1.29	1.08	1.17	1.17	I	1.57	1.72	1.59	1.73	I	1.74	1.71	1.90	1.91	I	1.91	1.91	1.88	1.85	I
1.66	1.64	1.83	1.79	I	2.02	2.01	1.99	1.98	I	1.75	1.72	1.94	1.95	I	1.92	1.93	2.13	1.96	I
1.91	1.89	1.75	1.69	I	1.69	1.69	.92	.00	I										

AVERAGE FAST DISASSEMBLY QUEUE AFTSKR

AFT SKIRT

.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I										

MEAN WEST DISASSEMBLY FACILITY CONTENT AFTSKR

AFT SKIRT

.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.70	I	.33	.32	.65	.62	I	.92	.90	.95	1.16	I	.98	1.14	1.22	1.21	I
1.19	1.45	1.49	1.21	I	1.15	1.41	1.43	1.20	I	.94	1.06	1.15	1.18	I	1.14	1.15	1.13	1.17	I
1.13	1.14	1.39	1.18	I	1.12	1.13	.37	.00	I										

MEAN WEST DISASSEMBLY QUEUE AFTSKR

AFT SKIRT

.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.00	I	.00	.00	.00	.00	I										

MEAN UNITS AVAILABLE AT ETR OR UTAH AFTSKR

AFT SKIRT

.00	.00	.00	.00	I	.00	.00	.00	2.71	I	7.43	5.30	4.59	2.91	I	3.95	2.96	1.98	2.36	I
1.63	1.70	1.57	1.52	I	.84	1.76	1.95	1.35	I	1.69	1.69	1.30	1.56	I	1.60	1.01	1.01	1.14	I
1.95	1.93	1.41	1.16	I	1.35	1.70	1.68	1.72	I	1.84	1.54	1.50	1.87	I	1.87	1.81	1.51	1.75	I
[illegible]	1.48	1.74	1.58	I	1.69	1.82	4.25	6.97	I										

MEAN UNITS AVAILABLE AT WTR AFTSKR

AFT SKIRT

.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I	.00	.00	.00	.00	I
.00	.00	.00	.84	I	2.04	1.57	1.03	.82	I	.74	.99	1.02	1.45	I	2.32	1.68	1.59	1.72	I
1.79	1.07	1.55	2.06	I	1.92	1.20	1.63	2.50	I	3.10	2.11	2.03	2.08	I	2.29	2.07	2.00	1.97	I
2.10	1.89	1.21	1.81	I	2.06	2.21	5.55	6.76	I										

Figure 10. (Continued).

AFT SKIRT

EARLY YEAR HARDWARE ASSIGNMENTS PER FLIGHT AFTSKR

FLT. NO.	MEAN NEW	ROUNDED UP NEW
1	2.00	2
2	2.00	2
3	2.00	2
4	2.00	2
5	2.00	2
6	.00	0
7	.00	0
8	.00	0
9	.00	0
10	.00	0
11	.00	0
12	.00	0
13	.00	0
14	.08	1
15	.68	0
16	.40	0
17	.29	0
18	.04	0
19	.00	0
20	.04	0
21	.00	0
22	.12	1
23	.68	0
24	.24	0
25	1.32	1
26	.24	0
27	.00	0

FLIGHTS	NEW	LOST	WORNOUT	LEFT
-7	13.92	5.88	.00	7.04
6.	25.20	14.12	.00	11.08
445	122.44	106.88	.12	15.44
ALL	133.00	119.00	.16	13.84

MEAN JUTTE UNITS REFURBABLE 11.12

MEAN POTENTIAL UNIT USES LEFT 441.92

LTU 1461 0 331 119 0

Figure 10. (Concluded).

SUBSYSTEM AFT SKIRT   UNITS PER FLIGHT 2

CALENDAR YEAR	FISCAL YEAR/ QUARTER	LAUNCH NUMBER	LAUNCH DATE	NEW HARDWARE REQUIREMENTS: MINIMUM ASSY TIME ASSUMPTION: NEW UNITS REQUIRED	NEW HARDWARE REQUIREMENTS: ASSIGNMENT NEW/ REFURB
1978	79/1			2	
1979	79/2			0	
	79/3			2	
	79/4	1	9/31/79	2	2N /0R
	80/1	2	12/31/79	2	2N /0R
1980	80/2	3	3/3/80	2	2N /0R
	80/3	4	6/1/80	0	2N /0R
	80/4	5	8/1/80	1	2N /0R
		6	9/30/80		0N /2R
	81/1	7	12/31/80	1	0N /2R
1981	81/2	8	1/15/81	2	0N /2R
		9	2/15/81		1N /1R
	81/3	10	4/15/81	1	0N /2R
		11	5/15/81		1N /1R
		12	6/15/81		0N /2R
	81/4	13	7/15/81	0	0N /2R
		14	8/15/81		0N /2R
		15	9/15/81		0N /2R
		16	9/28/81		2N /0R
	82/1	17	10/15/81	1	0N /2R
		18	11/15/81		1N /1R
1982	82/2	19	1/15/82	4	0N /2R
		20	1/28/82		0N /2R
		21	3/15/82		0N /2R
		22	3/28/82		0N /2R
	82/3	23	4/15/82	2	0N /2R
		24	5/15/82		1N /1R
		25	5/28/82		0N /2R
		26	6/15/82		0N /2R
	82/4	27	7/15/82	2	2N /0R
		28	7/28/82		
		29	8/15/82		
		30	9/15/82		
		31	9/28/82		

"INCREMENT 2" MEANS THE FIRST 21 OPERATIONAL FLIGHTS, I.E., FLIGHTS 7-27.

"NEW/REFURB: 1N/1R " MEANS 1 NEW AFT SKIRT AND 1 REFURBISHED AFT SKIRT MAKE UP THE FLIGHT SET OF 2 AFT SKIRTS.

"REQUIRED" MEANS THE LATEST QUARTER FOR ON-DOCK DELIVERY TO THE LAUNCH SITE TO MAKE THE INDICATED FLIGHT ASSIGNMENT.

Figure 11. DDT&E and increment 2 hardware assignments.

I. Sensitivity Studies

The sensitivity of new hardware quantities to various design and logistics parameters is important to an understanding of the uncertainties in hardware procurement planning and budgeting. Four SRB subsystem components were selected for illustration. These components are representative of the major SRB subsystems and thus their sensitivities can be used to determine the sensitivity of other SRB subsystems. The subsystem components which were simulated are as follows:

Major Subsystem	Subsystem Component Simulated
Solid Rocket Motor	Nozzle
Electronics and Instrumentation	Aft IEA
Thrust Vector Control	Actuator
Structures	Aft Skirt

A baseline case was run for each of the four subsystem components. Input data for these cases are shown in Table 10. The logistics parameters which were chosen for perturbation are those which were initially thought to have the greatest effect on hardware quantity requirements. To ensure the validity of the results, several values of each parameter were selected above and below the baseline value. This procedure was used to minimize the chance of error caused by random variation of mean values. This technique was not used in testing the sensitivity to changes in refurbishment time because of the apparent insensitivity of this parameter. The cases of 0 percent total attrition were set up to have a 0 percent probability of sinking as well as a 0 percent probability of loss for all units.

The learning curve percentages for the WTR were assumed to be a constant 4 percent above the corresponding ETR value. When ETR learning was 100 percent, WTR learning was also assumed to be 100 percent. Each study was given a case number to aid identification. The various cases which were investigated in the course of this study are shown in Table 11.

The results are presented in Tables 12 through 15. Inspection of the tabular results reveals that total attrition percentage is by far the most sensitive parameter tested in this study. Neither refurbishment time nor learning curve percentage have a significant effect on total hardware quantity requirements.

In general, changes in any parameter which caused an increase in the number of new units required also caused a corresponding decrease in the number of units which were worn out. This phenomenon occurs

TABLE 10. BASELINE CASE INPUT DATA FOR SRB SENSITIVITY STUDY

	Nozzle	Aft IEA	Aft Skirt	TVC Actuator
Assembly (SMAB) + Prelaunch Time	29.20	29.20	29.20	29.20
Total Attrition Percent	3.2	2.9	2.9	3.7
Maximum Uses Before Wornout	20	20	40	20
Time for Flight, Retrieval, Unload	4.0	4.0	4.0	4.0
Disassembly Duration	29.2	10.9	16.4	16.4
Transport to Refurb	8.0	0.0	0.0	0.0
Refurb Duration for First Unit	74.0	7.0	29.0	29.0
Transport from Refurb	22.0	0.0	0.0	0.0
Shared Subsystem Code (=1 If Shared)	1	0	0	0
ETR Assembly Learn Curve Percent Slope	93.00	93.00	93.00	93.00
ETR Disassembly Learn Curve Percent Slope	93.00	93.00	93.00	93.00
ETR Refurb Learn Curve Percent Slope	93.00	93.00	93.00	93.00
WTR Assembly Learn Curve Percent Slope	97.00	97.00	97.00	97.00
WTR Disassembly Learn Curve Percent Slope	97.00	97.00	97.00	97.00
WTR Refurb Learn Curve Percent Slope	97.00	97.00	97.00	97.00
Sinking Probability Percent	0.2	0.2	0.2	0.2
Number of Units Per Shi[illegible]et	1	1	1	2

NOTE: All times are in calendar days.

TABLE 11. SRB SENSITIVITY STUDY CASES

Subsystem Component	Refurb Turnaround Time (Days)	Case No.	Total Attrition Percentage	Case No.	ETR Learning Curve Percentage Slope	Case No.
			0	111	85	121
	30	101	2	112	89	122
Nozzle	Baseline 74	100	Baseline 3.2	100	Baseline 93	100
	100	102	4	113	97	123
			6	114	100	124
			10	115		
			20	116		
			0	211	85	221
	3	201	2	212	89	222
Aft IEA	Baseline 7	200	Baseline 2.9	200	Baseline 93	200
	15	202	4	213	97	223
			6	214	100	224
			10	215		
			20	216		
			0	311	85	321
	15	301	2	312	89	322
Aft Skirt	Baseline 29	300	Baseline 2.9	300	Baseline 93	300
	60	302	4	313	97	323
			6	314	100	324
			10	315		
			20	316		
			0	411	85	421
	15	401	2	412	89	422
TVC Actuator	Baseline 29	400	Baseline 3.7	400	Baseline 93	400
	60	401	6	413	97	423
			10	414	100	424
			20	415		

TABLE 12. NOZZLE STUDIES

CASE I.D. NO.	SRB SUBSYS NAME	CASE TITLE	ETR NEW MEAN (S.DEV)	ETR LOST MEAN (S.DEV)	ETR W/O MEAN (S.DEV)	WTP NEW MEAN (S.DEV)	WTP LOST MEAN (S.DEV)	WTP W/O MEAN (S.DEV)	TOTAL NEW MEAN (S.DEV)	TOTAL LOST MEAN (S.DEV)	TOTAL W/O MEAN (S.DEV)
100	NOZZLE	BASELINE	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	83.12 ([illegible])	27.15 ([illegible])	23.24 ([illegible])
101	NOZZLE	30 DAY REFURB	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	77.62 (3.7[illegible])	27.16 (5.42)	23.60 (2.73)
102	NOZZLE	100 DAY REFURB	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	81.6[illegible] (4.[illegible])	27.[illegible] ([illegible])	[illegible] ([illegible])
111	NOZZLE	0 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	67.30 (0.00)	[illegible].30 (0.[illegible])	32.0[illegible] (0.00)
112	NOZZLE	2 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	77.64 (2.37)	17.24 (4.24)	25.20 (2.33)
113	NOZZLE	4 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	37.94 (4.04)	33.52 (5.27)	21.72 (3.51)
114	NOZZLE	6 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	(NA)	99.75 (6.55)	50.76 (7.37)	14.60 (2.7[illegible])
115	NOZZLE	10 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	129.44 (7.44)	87.36 (9.23)	7.50 2.[illegible]
116	NOZZLE	20 PERCENT ATTRITION	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	203.05 (10.98)	170.48 (10.85)	1.72 (1.00)
121	NOZZLE	85 PERCENT ETR LEARNING	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	72.76 (3.93)	25.60 (5.33)	23.84 (2.63)
122	NOZZLE	89 PERCENT ETR LEARNING	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	79.76 (3.53)	27.08 (4.88)	24.03 (2.49)
123	NOZZLE	97 PERCENT ETR LEARNING	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	81.56 (5.29)	27.16 (5.39)	11.76 (2.10)
124	NOZZLE	100 PERCENT ETR LEARNING	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	NA (NA)	84.84 (5.35)	25.48 (5.75)	4.88 (1.36)

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TABLE 13. AFT IEA STUDIES

CASE I.D. NO.	SRB SOURCES NAME	CASE TITLE	ETR NEW MEAN (S.DEV)	ETR LOST MEAN (S.DEV)	ETR W/O MEAN (S.DEV)	WTR NEW MEAN (S.DEV)	WTR LOST MEAN (S.DEV)	WTR W/O MEAN (S.DEV)	TOTAL NEW MEAN (S.DEV)	TOTAL LOST MEAN (S.DEV)	TOTAL W/O MEAN (S.DEV)
200	AFTIEA	BASELINE	47.52 (3.[illegible])	19.40 ([illegible].27)	[illegible].52 (2.02)	19.03 (1.65)	5.40 (2.44)	7.88 (1.42)	65.[illegible]0 (3.51)	[illegible].30 (5.80)	26.40 (2.78)
201	AFTIEA	3 DAY REFURB	46.76 (3.[illegible])	19.44 (4.56)	21.54 (2.23)	19.36 (1.49)	5.72 (2.22)	7.88 (1.26)	65.12 (4.22)	25.16 (6.33)	29.52 (2.74)
202	AFTIEA	15 DAY REFURB	47.69 (3.4[illegible])	19.12 (4.33)	20.95 (2.22)	18.76 (1.33)	5.28 (2.15)	8.04 (1.33)	65.64 (3.69)	24.40 (5.13)	27.00 (2.64)
211	AFTIEA	0 PERCENT ATTRITION	36.00 (0.00)	0.00 (0.00)	26.00 (0.00)	16.00 (0.00)	0.00 (0.00)	10.00 (0.00)	52.00 (0.00)	0.00 (0.00)	3[illegible].00 (0.00)
212	AFTIEA	2 PERCENT ATTRITION	43.72 (2.07)	13.04 (3.33)	23.00 (2.04)	18.04 (1.17)	3.56 (1.87)	8.56 (0.96)	61.76 (2.53)	16.60 (4.40)	31.56 (2.[illegible]6)
213	AFTIEA	4 PERCENT ATTRITION	51.56 (3.53)	25.32 (4.[illegible]3)	18.72 (2.09)	20.28 (1.67)	7.44 (2.39)	7.20 (1.[illegible]3)	71.04 (4.07)	32.76 (5.[illegible])	25.[illegible]2 (2.[illegible])
214	AFTIEA	6 PERCENT ATTRITION	60.64 (3.95)	38.20 (5.52)	14.96 (2.44)	23.64 (2.70)	12.55 (3.33)	5.44 (1.38)	84.28 (5.24)	50.76 (6.71)	20.40 (2.[illegible])
215	AFTIEA	10 PERCENT ATTRITION	81.48 (6.65)	65.56 (8.30)	8.72 (2.31)	30.28 (3.57)	21.56 (3.97)	3.24 (1.20)	111.76 (7.76)	87.12 (9.07)	11.96 (2.[illegible])
216	AFTIEA	20 PERCENT ATTRITION	135.20 (10.70)	120.72 (11.20)	1.80 (1.22)	52.48 (6.[illegible]8)	46.80 (6.57)	0.[illegible]4 (0.[illegible])	187.68 (12.47)	173.52 (12.95)	2.64 (1.46)
221	AFTIEA	85 PERCENT ETR LEARNING	44.96 (3.00)	18.96 (4.43)	22.32 (2.13)	17.96 (1.71)	4.72 (2.47)	[illegible] (1.19)	62.92 (3.45)	23.68 (5.16)	31.84 (2.57)
222	AFTIEA	89 PERCENT ETR LEARNING	46.40 (2.78)	19.52 (4.33)	21.28 (2.13)	18.12 (1.16)	5.36 (2.34)	9.04 (1.42)	64.52 (3.42)	24.88 (5.48)	30.32 (2.83)
223	AFTIEA	97 PERCENT ETR LEARNING	48.56 (2.75)	19.68 (4.41)	19.32 (2.11)	18.80 (1.77)	5.16 (2.57)	8.08 (1.18)	67.36 (3.37)	24.84 (4.87)	27.40 (2.41)
224	AFTIEA	100 PERCENT ETR LEARNING	50.04 (3.81)	19.00 (4.33)	19.80 (2.70)	19.08 (1.68)	6.00 (2.54)	7.32 (1.24)	69.12 (4.43)	25.00 (6.23)	27.12 (3.41)

TABLE 14. AFT SKIRT STUDIES

CASE NO.	SUBSYS NAME	CASE TITLE	ETR NEW MEAN (S.DEV)	ETR LOST MEAN (S.DEV)	ETR R/O MEAN (S.DEV)	ATR NEW MEAN (S.DEV)	ATR LOST MEAN (S.DEV)	ATR R/O MEAN (S.DEV)	TOTAL NEW MEAN (S.DEV)	TOTAL LOST MEAN (S.DEV)	TOTAL R/O MEAN (S.DEV)
[illegible]	AFTSKR	BASELINE	35.92 ([illegible])	19.35 ([illegible])	4.72 (1.75)	13.40 (7.19)	5.64 (2.19)	0.00 (0.00)	49.32 ([illegible])	[illegible] ([illegible])	4.72 ([illegible])
[illegible]	AFTSKR	15 DAY REFURB	[illegible] ([illegible])	19.84 ([illegible])	6.44 ([illegible])	13.00 (1.32)	5.24 ([illegible])	2.76 (1.29)	[illegible] ([illegible])	[illegible] ([illegible])	[illegible] ([illegible])
302	AFTSKR	60 DAY REFURB	37.16 ([illegible])	[illegible] ([illegible])	3.92 (1.44)	14.24 (2.33)	5.72 ([illegible])	0.00 (0.00)	51.40 (4.36)	25.24 ([illegible])	[illegible] ([illegible])
311	AFTSKR	0 PERCENT ATTRITION	[illegible] ([illegible])	0.00 ([illegible])	[illegible] ([illegible])	9.00 ([illegible])	0.00 ([illegible])	0.00 ([illegible])	[illegible] ([illegible])	[illegible] ([illegible])	[illegible] ([illegible])
312	AFTSKR	2 PERCENT ATTRITION	31.69 (3.50)	13.95 (3.35)	7.96 (1.64)	11.44 (1.80)	3.44 ([illegible])	0.00 (0.00)	43.12 ([illegible])	17.40 ([illegible])	[illegible] ([illegible])
313	AFTSKR	4 PERCENT ATTRITION	41.32 (3.82)	26.56 (4.15)	5.16 (1.86)	16.08 (3.27)	8.32 (3.33)	0.00 (0.00)	57.40 (5.53)	[illegible] ([illegible])	[illegible] ([illegible])
314	AFTSKR	6 PERCENT ATTRITION	51.68 ([illegible])	39.48 (4.90)	2.56 ([illegible])	20.84 (3.43)	13.20 ([illegible])	0.00 (0.00)	74.52 (6.29)	52.68 ([illegible])	[illegible] ([illegible])
315	AFTSKR	10 PERCENT ATTRITION	74.24 (6.37)	[illegible] ([illegible])	0.96 ([illegible])	29.80 (4.57)	22.20 (4.37)	0.00 (0.00)	104.04 ([illegible])	86.36 (7.65)	[illegible] ([illegible])
316	AFTSKR	20 PERCENT ATTRITION	132.04 ([illegible])	[illegible] ([illegible])	[illegible] ([illegible])	52.48 (4.68)	45.55 ([illegible])	0.00 (0.00)	184.52 (12.84)	[illegible] ([illegible])	[illegible] ([illegible])
321	AFTSKR	85 PERCENT ETR LEARNING	32.48 ([illegible])	19.12 (5.12)	7.48 (1.50)	12.32 (1.65)	5.72 (2.79)	2.68 (1.14)	44.80 (3.90)	24.84 (5.10)	10.16 ([illegible])
322	AFTSKR	89 PERCENT ETR LEARNING	33.44 (3.75)	19.70 (3.87)	6.28 (1.35)	13.56 (2.02)	5.40 (2.30)	2.76 (1.15)	47.20 (3.84)	25.16 (4.07)	9.04 (1.75)
323	AFTSKR	97 PERCENT ETR LEARNING	36.52 (4.13)	18.52 (4.51)	4.28 (1.79)	13.84 (2.76)	5.96 (2.37)	0.00 (0.00)	50.36 (5.48)	24.48 (6.20)	4.28 (1.79)
324	AFTSKR	100 PERCENT ETR LEARNING	37.80 (4.06)	19.28 (4.43)	0.96 (0.84)	13.24 (2.53)	5.56 (2.69)	0.00 (0.00)	51.04 (5.57)	24.84 (5.93)	0.96 (0.84)

TABLE 15. TVC ACTUATOR STUDIES

CASE I.D. NO.	SRB SUBSYS NAME	CASE TITLE	ETR NEW MEAN (S.DEV)	ETR LOST MEAN (S.DEV)	ETR W/O MEAN (S.DEV)	WTR NEW MEAN (S.DEV)	WTR LOST MEAN (S.DEV)	WTR W/O MEAN (S.DEV)	TOTAL NEW MEAN (S.DEV)	TOTAL LOST MEAN (S.DEV)	TOTAL W/O MEAN (S.DEV)
400	TVCACT	BASELINE	104.08 (9.15)	48.88 (11.27)	35.40 (4.79)	42.00 (3.39)	13.92 (4.26)	12.64 (2.56)	146.08 (9.63)	62.80 (10.53)	49.34 (4.35)
401	TVCACT	15 DAY REFURB	99.68 (6.57)	45.52 (8.02)	39.28 (5.65)	39.92 (3.34)	14.56 (4.53)	15.20 (2.76)	139.60 (7.09)	60.08 (9.11)	54.08 (3.97)
	TVCACT	60 DAY REFURB	108.32 (5.09)	48.58 (10.00)	32.80 (3.95)	44.32 (4.30)	14.80 (5.32)	14.00 (2.67)	152.64 (8.57)	63.38 (10.43)	46.88 (4.43)
411	TVCACT	0 PERCENT ATTRITION	74.00 (0.00)	0.00 (0.00)	56.00 (0.00)	32.00 (0.00)	0.00 (0.00)	16.00 (0.00)	106.00 (0.00)	0.00 (0.00)	72.00 (0.00)
412	TVCACT	2 PERCENT ATTRITION	89.36 (5.52)	26.64 ([illegible])	43.60 (4.20)	37.52 (2.90)	7.84 (3.96)	14.32 (2.21)	126.88 (6.53)	34.48 (9.60)	57.92 (5.14)
413	TVCACT	6 PERCENT ATTRITION	126.08 (10.53)	79.68 (12.14)	27.60 (4.24)	51.36 (5.52)	26.48 (5.66)	9.60 (2.58)	177.44 (12.13)	106.16 (13.42)	37.20 (5.93)
414	TVCACT	10 PERCENT ATTRITION	161.92 (13.66)	126.64 (16.21)	17.44 (4.06)	65.56 (7.42)	46.48 (9.50)	5.52 (3.22)	228.43 (14.49)	173.12 (17.57)	22.96 (5.41)
415	TVCACT	20 PERCENT ATTRITION	264.56 (20.74)	244.48 (22.51)	3.36 (2.69)	108.32 (12.31)	93.76 (12.19)	1.12 (1.73)	372.88 (24.53)	338.24 (25.01)	4.48 (3.28)
421	TVCACT	85 PERCENT ETR LEARNING	98.72 (7.20)	48.08 (10.14)	39.44 (4.41)	37.44 (5.11)	14.08 (7.24)	15.84 (2.64)	135.16 (9.72)	62.16 (10.34)	55.28 (5.47)
422	TVCACT	89 PERCENT ETR LEARNING	101.68 (5.85)	47.92 (8.43)	38.88 (3.36)	40.48 (3.65)	14.40 (5.88)	15.52 (3.57)	142.16 (7.13)	62.32 (10.05)	54.40 (4.72)
423	TVCACT	97 PERCENT ETR LEARNING	107.68 (6.26)	47.52 (9.09)	33.52 (4.29)	42.80 (4.04)	14.88 (5.13)	12.72 (2.37)	150.48 (7.57)	62.40 (10.67)	46.24 (4.52)
424	TVCACT	100 PERCENT ETR LEARNING	111.92 (6.74)	47.12 (8.73)	35.88 (3.91)	42.56 (4.93)	14.56 (5.87)	12.48 (2.25)	154.48 (9.17)	61.68 (11.60)	43.36 (5.21)

in the refurbishment time and learning curve percentage studies because the increase in time required for a given operation means that an increased number of units will be tied up in this operation at any one time. This decrease in availability causes an increase in the number of new units required to meet the mission model. Because the mission model remains unchanged, the average number of uses per unit decreases as the number of units increases and this means that fewer units will be used to their wear-out point.

This same phenomenon occurs in the total attrition percentage studies, but for a different reason. As the attrition rate increases, the requirement for new units increases to facilitate replacement of the lost units. This increased attrition rate also means that fewer units will be used to their wear-out point.

The standard deviation tends to increase as the hardware quantity increases for each of the parameters studied. For most cases, however, the standard deviation remains approximately the same percentage of the mean. Using the total attrition percentage of the nozzle as an example, the standard deviation of new units required varies from 4 percent to 6.6 percent of the mean value.

The data for the refurbishment results are very sparse, and extrapolation of these data is ill advised. Additional studies are recommended if it becomes necessary to investigate significant changes in refurbishment time. The total attrition percentage data appears to be very consistent for all subsystem components. Refurbishment time and learning curve percent are relatively important in the determination of new hardware quantities at low attrition rates, but are rapidly overshadowed as the attrition rate increases. Any new hardware quantity which is derived from this study should be tempered by the standard deviation associated with the quantity. The BOSIM-V4 computer program is a probabilistic simulation model of a "real world" system, and these variations of mean values are to be expected from such a system. More detailed sensitivity studies are presented in Reference 17. The effect of loss versus reuse of the DDT&E hardware is studied in Reference 18. A study of the sensitivity of SRM motor quantities to attrition is presented in Reference 19.

J. Facility Capacity Studies

Facility capacity refers to the maximum number of units which can be simultaneously serviced. The service may be disassembly, refurbishment, or other simulated facility in BOSIM. Briefly, the approach to the problem is as follows. First, the refurbishment facility occupancy versus time is determined with no limits placed on the number of units in refurbishment at the same time; i.e., unlimited capacity. Using the maximum occupancy level as a starting point, smaller capacity values are input in later simulation runs until the hardware quantities become large

relative to the unlimited capacity quantities. The lower refurb capacity prevents some units from being refurbished promptly after disassembly since they must wait until earlier arrivals leave the facility. This delay, in effect, lengthens the turnaround time for some units causing a need for more new units in the system to supply scheduled launches.

Aft skirt refurbishment is taken as an example. The refurbishment facility usage levels were first determined with unlimited capacities to provide reference cases. The usage level was determined for each quarter from the beginning of FY79 through FY90. During each simulated quarter, the level of occupancy multiplied by the hours at that level was accumulated. When divided by the hours in a quarter, a time integrated average occupancy level results. The levels from 25 simulation repetitions using different random number strings to place losses are averaged to produce the results shown in Figures 12 through 16. The same method was used to produce quarterly queue (waiting line) occupancy data. In addition, the maximum usage level during each quarter was kept in the computer memory. The maximum of the 25 simulation repetition maximums was printed and is plotted in some of the figures. This maximum usage level is an exact value under the current groundrules requiring on-time launches and not accounting for random variations in times between launch and arrival at the refurbishment facility.

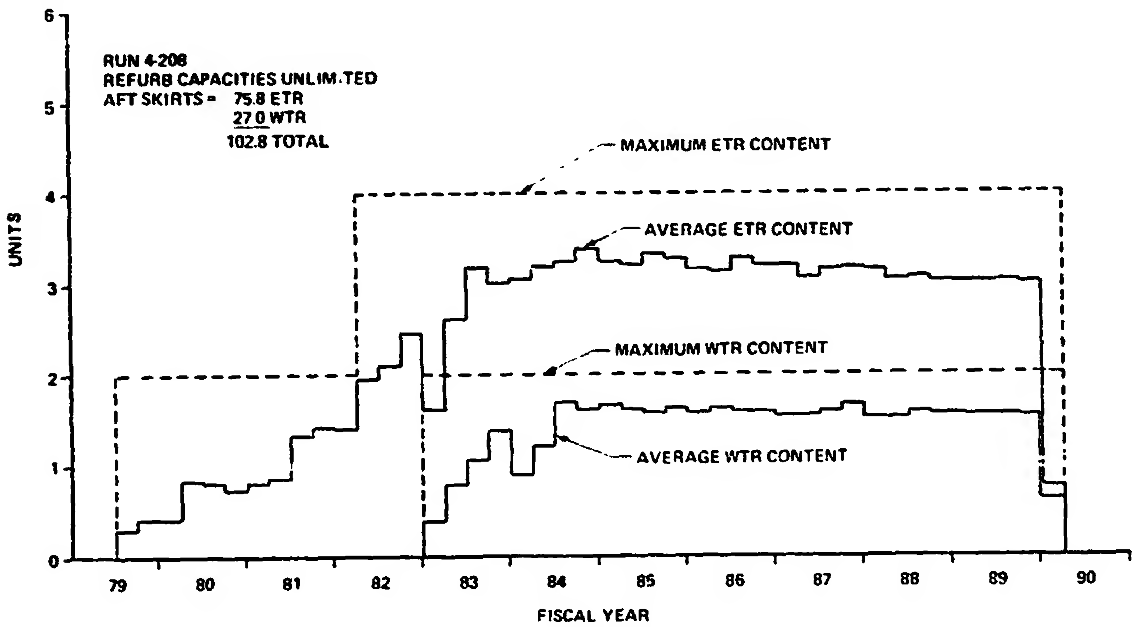


Figure 12. Aft skirt (Run 4-208).

Figure 12 shows the aft skirt refurbishment facility usage levels when capacities at ETR and WTR are unlimited. The aft skirt subsystem is non-shared and there is one unit per SRB shipset. When the ETR capacity is four or more, the results will be the same as in Figure 13 since the maximum content is four.

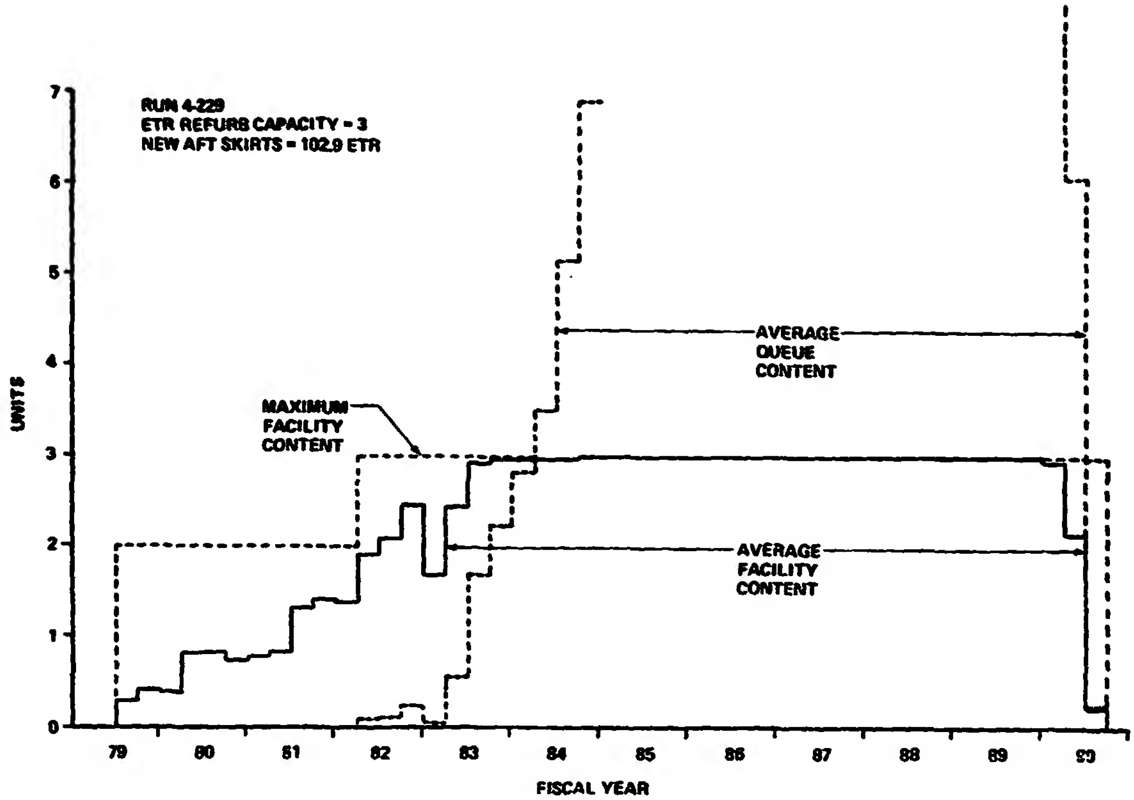


Figure 13. Aft skirt (Run 4-229).

When ETR capacity is reduced to three aft skirts, the large queue shown in Figure 13 occurs and the ETR new quantity goes up about 27 percent. A capacity of two units at ETR (Fig. 14) produces a requirement for about 3.4 times as many units. A WTR capacity of two or more produces no waiting and results in a requirement for an average of 27 new aft skirts at WTR. The usage levels are shown in Figure 14. Figure 15 shows the WTR levels when the WTR capacity is one unit. The new aft skirts required are almost four times as much as when the WTR capacity is two units.

Figure 16 shows the aft skirt unit levels when the refurbishment facility capacities are varied as shown by the dashed lines. The variable capacities were constructed by rounding up the average facility contents from Figure 12 to integer values. No significant increase occurs in the numbers of aft skirts required compared to the infinite refurbishment capacity case (Fig. 12). Table 16 summarizes the aft skirt results. Further details of this example are detailed in Reference 20, and an additional hardware flow analysis is described in Reference 21.

A facet of refurbishment processing not accounted for is the existence of multiple, sequential work stations. The capacities used in

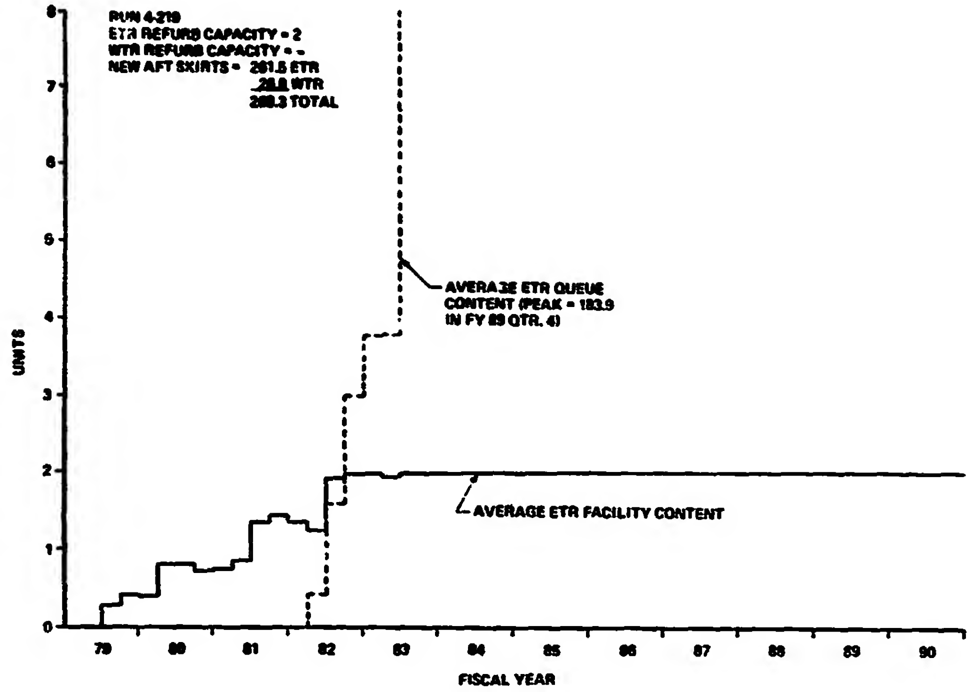


Figure 14. Aft skirt (Run 4-219).

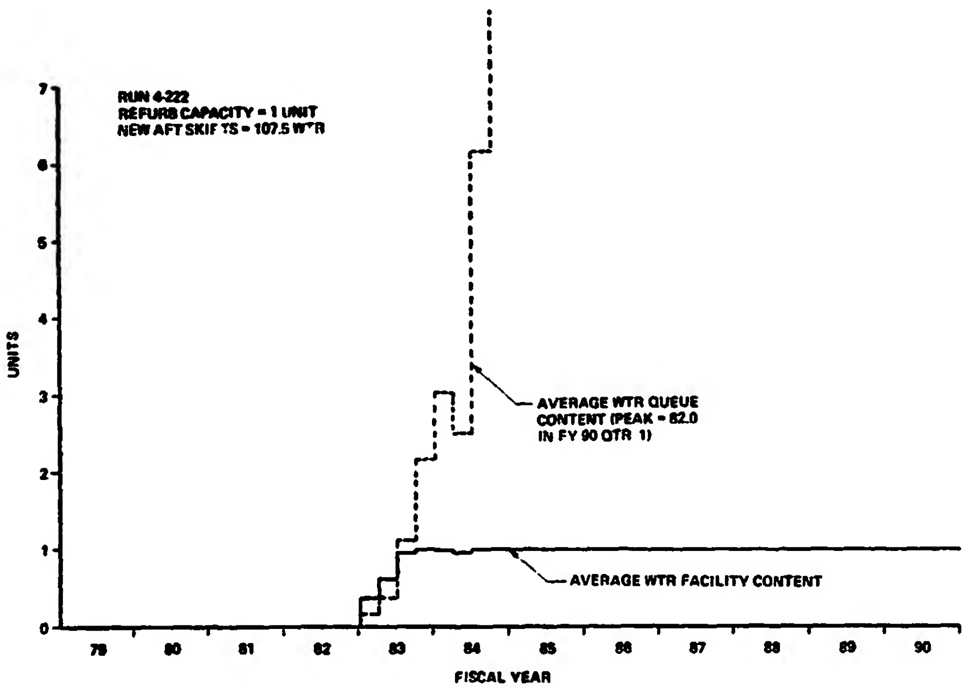


Figure 15. Aft skirt (Run 4-222).

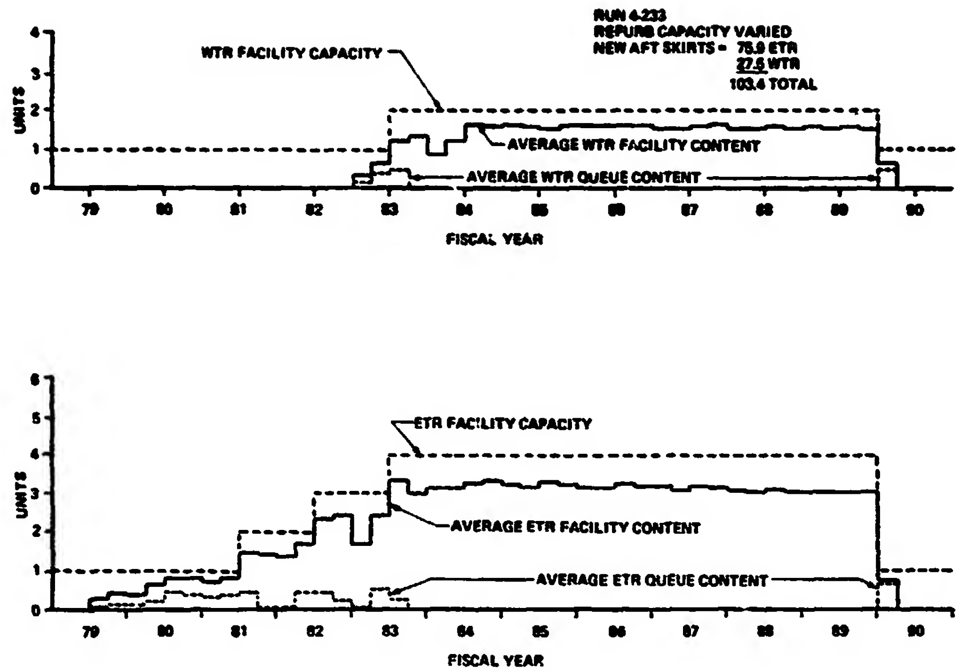


Figure 16. Aft skirt (Run 4-233).

TABLE 16. AFT SKIRT SUMMARY

Refurbishment Facility Capacity (Units)	Total New Units Required	Reference Figure Number
Unlimited ETR (Same as 4)	75.8	3-19
Varied up to 4 ETR	75.9	3-23
3 ETR	102.9	3-20
2 ETR	261.5	3-21
Unlimited WTR (Same as 2)	27.0	3-19
Varied up to 2 WTR	27.5	3-23
1 WTR	107.5	3-22
Initial Refurb Duration = 29 days Crawford Learning Curve Slope = 93 percent ETR, 97 percent WTR Average Refurb Duration = 16 days Initial Turnaround Time = 78.6 days		

this study are based on the assumption that one hardware unit occupies one unit of refurbishment facility capacity to the complete exclusion of other hardware units. In reality, units may move from one part of the refurbishment process to the next, allowing a subsequent unit to start refurbishment before the first is finished. No data have been available to permit modeling of sequential activities within the refurbishment process. If sequential stations were accounted for, the required hardware and capacities estimates would be lower in some cases.

Much more analysis will be required to establish facility buildup profiles and to determine when and where extra work shifts will be advisable. None of the above items are needed as much as definition of the existence and modes of operation of sequential work stations within the refurbishment processes. Sequential processing can make drastic reductions in the capacities required. Costing data to permit tradeoff analyses of hardware quantities versus refurbishment facility capacity is needed.

III. HARDWARE DELIVERY SCHEDULES

The basic logistics simulation model output is the average number of new units needed per fiscal quarter to sustain the traffic model. These data are converted into production schedules by considering: (1) the confidence in the simulation results and the need to insure that either a new or refurbished component of each subsystem will be available for launching on schedule, (2) the economics of smooth versus irregular production, (3) the cost penalties incurred when there are 1 to 2 year breaks in production, and (4) the desire to reduce early year program funding due to budget constraints. The computer program which performs the production smoothing is described. The results of a production smoothing analysis have an associated confidence level; i.e., a probability of meeting the hardware requirements of a specific traffic model to avoid late launches. If hardware is delivered in advance, the probability of meeting the flight schedule increases. However, advanced delivery of hardware increases early year program funding which is constrained. Thus the increased confidence in meeting the traffic model must be weighed against the corresponding increase in early year program funding. These conflicting conditions and their resolution are described.

A. Manufacturing Rates

Hardware manufacturing rates for SRB components during FY78/79/80 are more or less constant. These rates and time frames correspond to the manufacture of DDT&E flight hardware. The problem is that of deciding what manufacturing rate to select for the subsequent production of operational flight hardware. This decision point corresponds to the

termination of Increment 1 and the beginning of Increment 2 of the SRB Project. A critical factor is the consideration that the eventual mission model flown may not be firmly decided at the end of DDT&E hardware manufacture. DDT&E hardware manufacture ends for the aft skirt before the first flight. It seems probable that the experience and results of the six DDT&E flights and perhaps even the first few operational flights will be considered before a final decision is made to build up the mission model to the level of 60 flights/year, or to peak at 15 flights/year for example. The DDT&E flights and first few operational flights cover a time frame of approximately 2 years. Further, approximately the first six operational flights can be performed on schedule with recovered DDT&E flights hardware. The necessity for additional hardware (beyond that purchased for DDT&E flights) does not arise until mid FY82. At that time, if it is still desired to continue the mission model buildup to 60 flights/year, new hardware must be manufactured rapidly.

Therefore, between mid FY80 and mid FY82 the following situation exists: (1) the eventual mission model to be flown is not known and (2) there is no necessity to manufacture hardware to run the mission model. So the question arises whether to continue manufacture of hardware during that period, and at what rate. The assumption to date on hardware manufacture is that there is essentially one production line set up to produce DDT&E and operational flight hardware units. Cost savings from the learning curve effect are necessary to achieve low total hardware cost and cost per flight, and these savings are only achievable with a continuous, smooth production plan. A significant production gap can be very costly in start-up and the re-learning involved. However, continuing the DDT&E manufacturing rate will lead to significant overproduction resulting in high early year operational flight program funding and in wasted hardware if the outcome of the DDT&E flights lead to a decision to sharply curtail the mission model. Figure 17 depicts the situation graphically. The cross-hatched step function shows the cumulative new units required to support two traffic models, one peaking at 60 flights/year and the other at 15 flights/year. The solid line beginning in FY78 represents the accumulation of hardware from smooth DDT&E flight production. The dotted lines represent manufacturing rate strategies beyond DDT&E which are possible to meet the requirement for operational flight hardware.

In mid FY82 when it is assumed that a firm decision can be made as to the subsequent flight buildup schedule and peak flights/year, the manufacturing rate which must then be initiated is critically dependent on what has been manufactured for the previous 2 years. If there has been a production gap, for example, and it is desired to follow the current baseline buildup plan to 60 flights/year, then a prohibitively high manufacturing rate will probably result. Prohibitively high means that the available tooling is inadequate for the required manufacturing rate. The penalty is the need to purchase additional sets of tooling and go to two or three shift operation. However, in this situation if the DDT&E manufacturing rate had been continued, then sufficient hardware

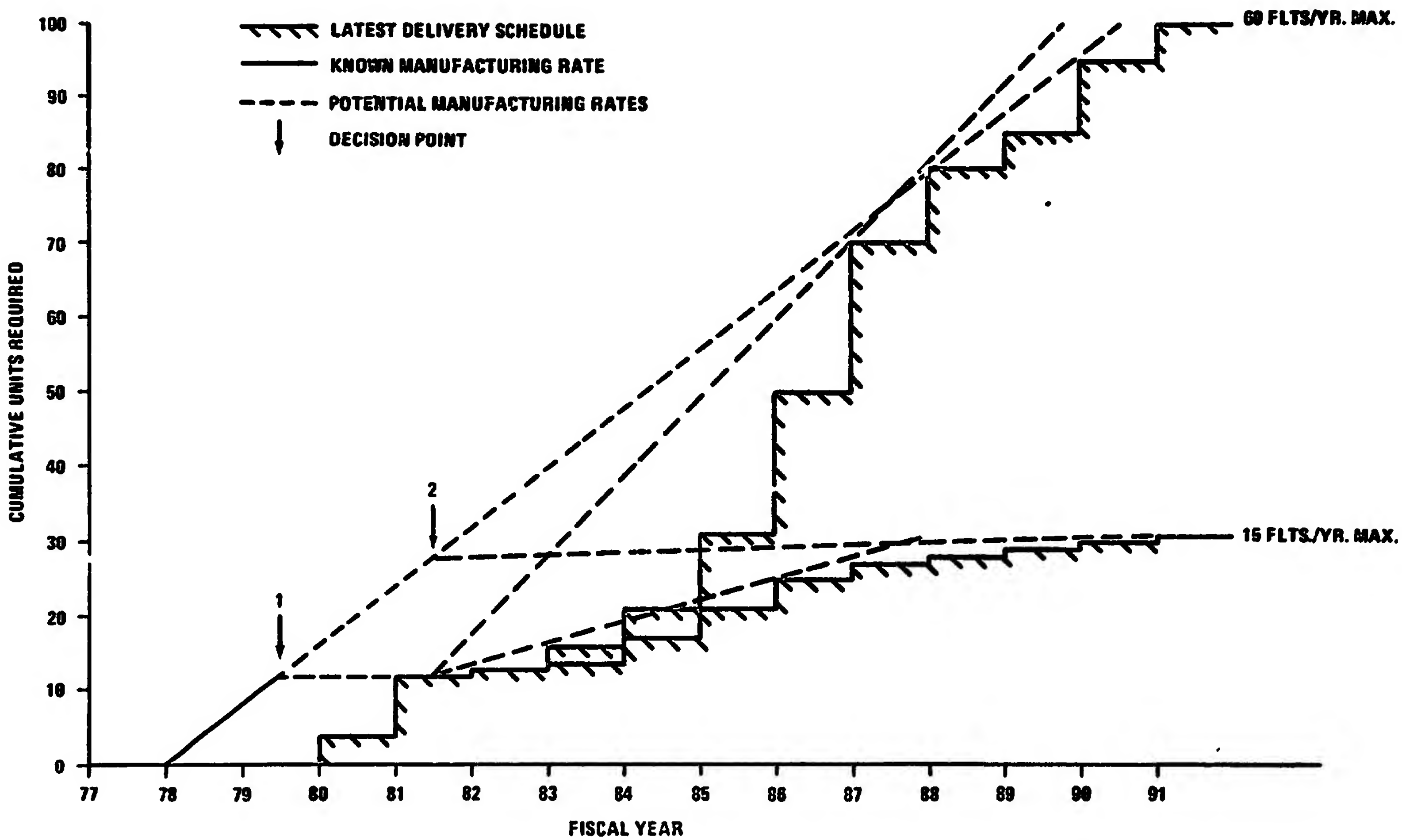


Figure 17. General problem schematic.

would have accumulated and only a moderate or no increase in manufacturing rate would be required to meet the hardware requirement as the mission model builds up.

Putting these factors in perspective, the general problem can be described as: the time period between the end of DDT&E manufacture and the time when a definitive mission model decision can be made is a time period when the strategy followed must be optimized to avoid severe cost penalty.

B. Production Smoothing

Production smoothing analysis is done by the GRAH computer program. The basic BOSIM output of the quarterly requirements for new hardware to support the launch rate is highly irregular. The interaction of mission model, attrition, turnaround time and hardware wearout lead to irregular requirements for new hardware. Figure 18 is an example for the forward cylinder, a portion of the Solid Rocket Motor case. Between 1983 and 1987 the requirements are particularly erratic. Figure 19 shows a bar graph plot of these requirements, and Figure 20 shows a plot of the cumulative requirements. GRAH analyzes the data of Figure 20 and determines the minimum level manufacturing rate which just meets the hardware requirements. Typical results are shown in Figure 21. The first section of smooth production corresponds to the known production of DDT&E hardware. Then beginning in FY80 GRAH determines the minimum level manufacturing rate for the production of operations flights hardware. Appendix C and Reference 22 provide a more detailed description of GRAH. Figure 22 demonstrates how the smooth production is broken down into quarterly production. Tables 17 and 18 present the results of applying GRAH to the full complement of SRB subsystems.

NEW HARDWARE REQUIREMENTS

SUBSYSTEM	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
FWD CYLINDER — PER YEAR	0	0	12	12	12	27	39	22	9	5	10	10	22	0	0
FWD CYLINDER — CUMULATIVE	0	0	12	24	36	63	102	124	133	138	148	158	180	180	180

Figure 18. Example of new hardware requirements for forward cylinder.

Obviously many production strategies can be followed to meet a given cumulative required curve. Two or three step increases in production can be made before searching for a minimum level. Figure 23 illustrates this for the aft tunnel.

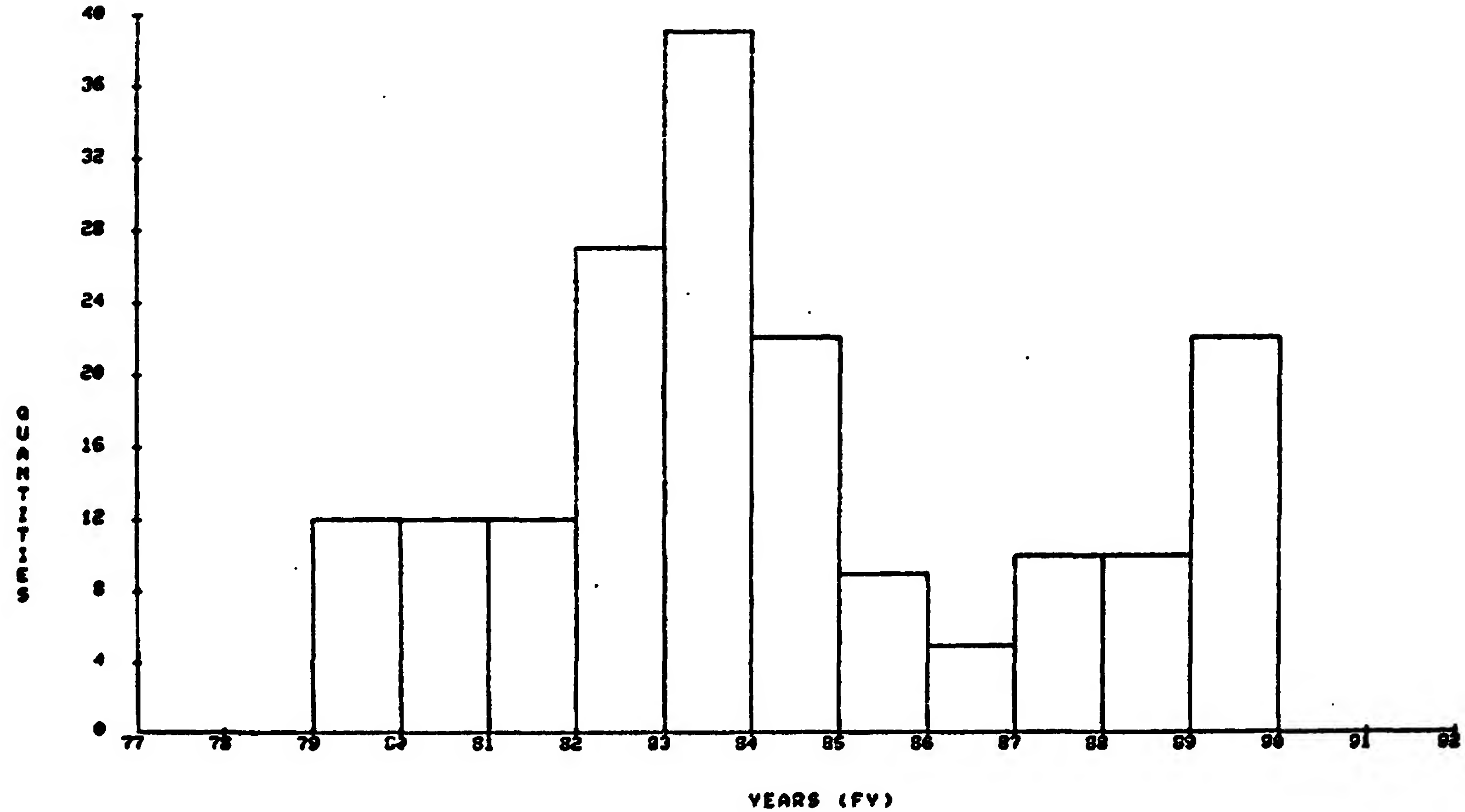


Figure 19. Bar graph of new requirements for forward cylinder.

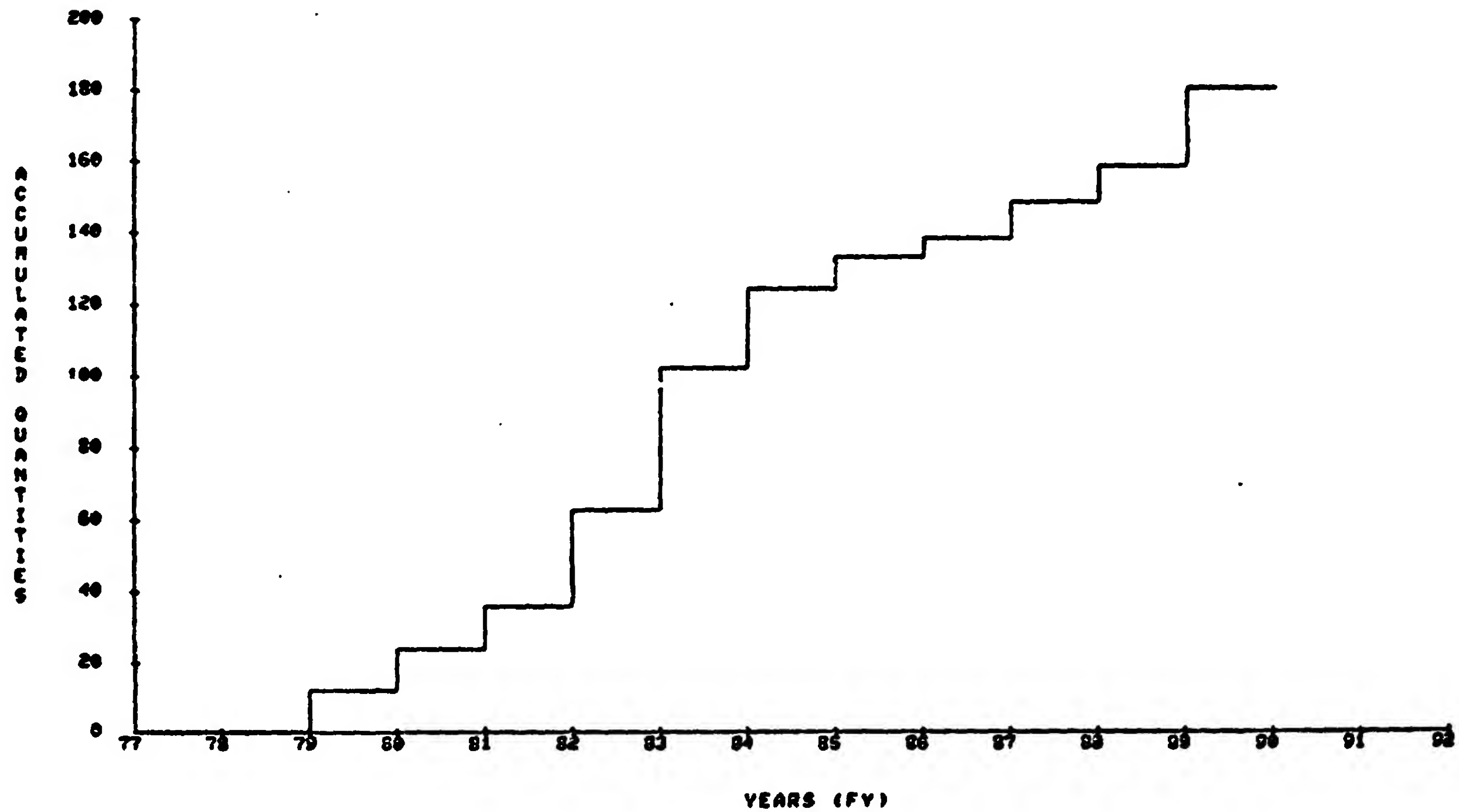


Figure 20. Plot of new cumulative requirements for forward cylinder.

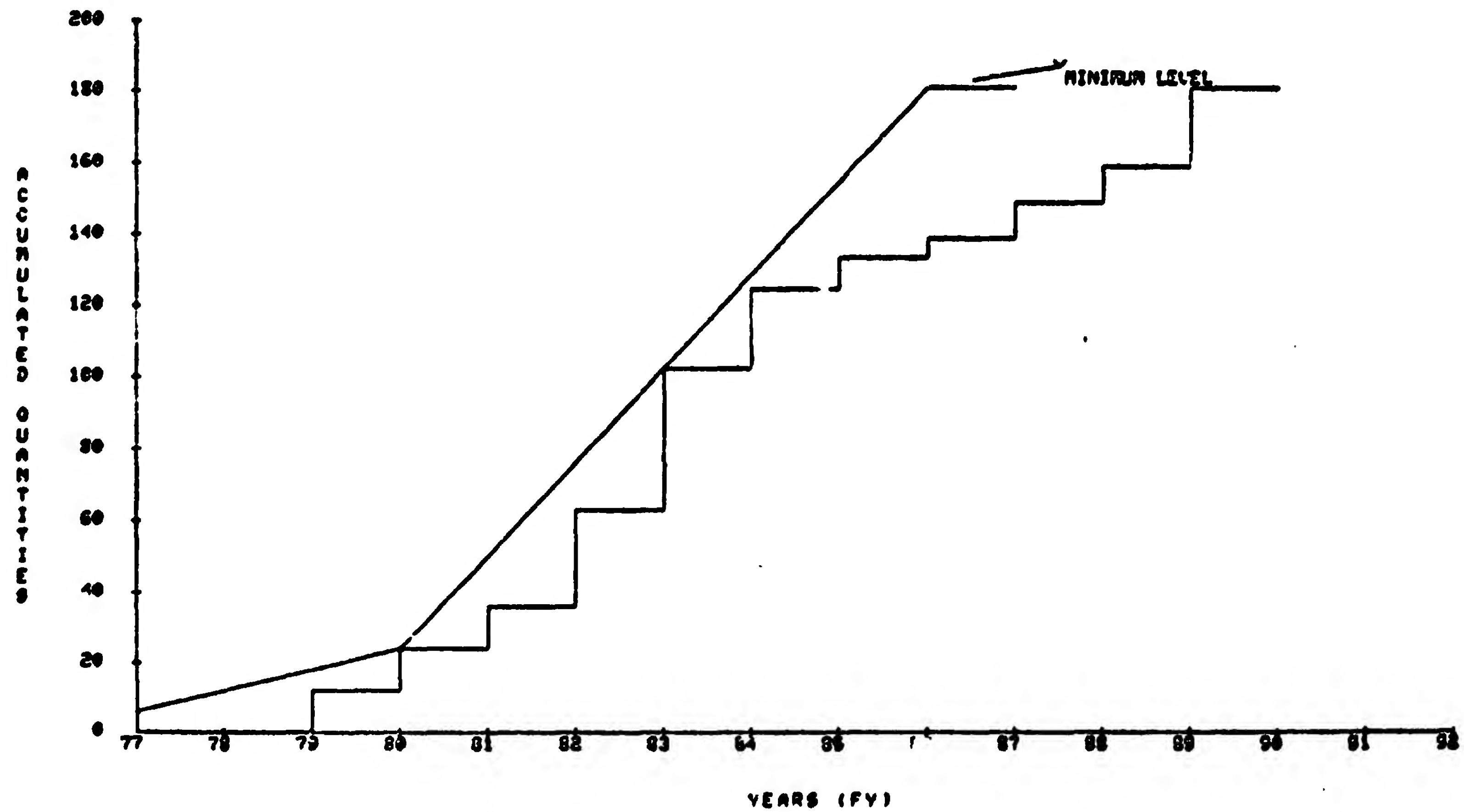


Figure 21. GRAH analysis showing minimum level manufacturing rate.

MINIMUM LEVEL HARDWARE REQUIREMENTS

SUBSYSTEM	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
FWD CYLINDER	6	6	6	6	26	26	26	26	26	26	0	0	0	0	0
FWD CYLINDER	6	12	18	24	50	76	102	128	154	180	180	180	180	180	180

HARDWARE REQUIREMENTS -- PRESENTED IN QUARTERS

FWD CYLINDER

FY 77				FY 78				FY 79				FY 80				FY 81			
1	1	2	2	1	1	2	2	1	1	2	2	1	1	2	2	6	6	7	7

FY 82				FY 83				FY 84				FY 85				FY 86			
6	6	7	7	6	6	7	7	6	6	7	7	6	6	7	7	6	6	7	7

FY 87				FY 88				FY 89				FY 90				FY 91			
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 22. Smooth production broken down into quarterly production.

TABLE 17. HARDWARE REQUIREMENTS

Subsystem	Year 79	80	81	82	83	84	85	86	87	88	89	90	Total
SRB													
Aft Cylinder	8	16	10	18	39	20	5	6	13	12	22	6	175
Fwd Cylinder	8	16	10	17	38	21	4	5	11	14	20	6	170
Other Segments	4	8	5	8	18	10	2	3	6	6	11	4	85
Aft Stiff Tees	16	32	0	8	37	25	17	16	14	16	18	3	202
Nozzle	4	8	4	9	19	10	2	3	7	5	11	4	86
Compliance Ring	4	8	5	10	19	11	3	3	6	7	10	4	90
Insulation	4	14	26	46	84	112	120	120	120	120	120	4	890
Igniter	4	8	4	9	19	10	2	3	6	6	10	3	84
Propellant	4	14	26	46	84	112	120	120	120	120	120	4	890
E+I													
E+I (DDT+E Unique)	4	8											12
E+I Fwd Skirt	4	8	0	2	10	7	7	8	7	6	8	1	68
E+I Aft IEA	4	8	0	1	10	7	6	8	7	6	7	2	66
TVC													
Actuator	8	16	1	6	26	18	12	11	17	15	12	4	146
Power Supply	8	16	0	6	24	17	10	10	18	16	12	2	139
Structures													
Nose Cap	4	14	26	46	84	112	120	120	120	120	120	4	890
Nose Frustum	4	8	0	3	12	5	3	2	3	?	4	2	49
Separation Ring	4	14	26	46	84	112	120	120	120	120	120	4	890
Fwd Skirt	4	8	1	2	9	6	3	3	3	4	5	1	49
System Tunnel	4	8	0	1	9	5	3	4	5	3	5	1	48
ET Attach Ring	4	8	0	2	9	5	4	4	4	3	5	1	49
SRB/ET Attach Struts	4	8	0	2	10	6	4	3	4	3	5	0	49
Aft Skirt	4	8	0	3	12	6	3	2	3	4	4	2	51
Thermal Shield	4	14	26	46	84	112	120	120	120	120	120	4	890
Recovery													
Pilot Chute	4	14	26	46	84	112	120	120	120	120	120	4	890
Drogue Chute	4	8	1	8	16	16	16	16	15	16	17	3	136
Main Chute	12	24	2	23	48	49	48	49	45	46	50	10	406
Recovery Aids	12	24	1	3	33	23	15	28	16	19	23	4	201

TABLE 18. MINIMUM LEVEL MANUFACTURING SCHEDULE

Subsystem	Year												Total
	79	80	81	82	83	84	85	86	87	88	89	90	
SRM													
Aft Cylinder	8	21	21	21	21	21	21	21	20				175
Fwd Cylinder	8	21	21	21	21	21	21	21	15				170
Other Segments	4	10	10	10	10	10	10	10	10	1			85
Aft Stiff Tees	16	32	32	32	32	32	26						202
Nozzle	4	10	10	10	10	10	10	10	10	2			86
Compliance Ring	4	11	11	11	11	11	11	11	9				90
Insulation	4	14	26	46	84	112	120	120	120	120	120	4	890
Igniter	4	10	10	10	10	10	10	10	10				84
Propellant	4	14	26	46	84	112	120	120	120	120	120	4	890
E+I													
E+I (DDT&E Unique)	4	8											12
E+I Fwd Skirt	4	8	8	8	8	8	8	8	8				68
E+I Aft IEA	4	8	8	8	8	8	8	8	6				66
TVA													
Actuator	8	16	16	16	16	16	16	16	16	10			146
Power Supply	8	16	16	16	16	16	16	16	16	3			139
Structures													
Nose Cap	4	14	26	46	84	112	120	120	120	120	120	4	890
Nose Frustum	4	8	8	8	8	8	5						49
Separation Ring	4	14	26	46	84	112	120	120	120	120	120	4	890
Fwd Skirt	4	8	8	8	8	8	5						49
Systems Tunnel	4	8	8	8	8	8	4						48
ET Attach Ring	4	8	8	8	8	8	5						49
SRB/ET Attach Struts	4	8	8	8	8	8	5						49
Aft Skirt	4	8	8	8	8	8	7						51
Thermal Shield	4	14	26	46	84	112	120	120	120	120	120	4	890
Recovery													
Pilot Chute	4	14	26	46	84	112	120	120	120	120	120	4	890
Drogue Chute	4	13	13	13	13	13	13	13	13	13	13	2	136
Main Chute	12	39	39	39	39	39	39	39	39	39	39	4	406
Recovery Aids	12	24	24	24	24	24	24	24	21				201

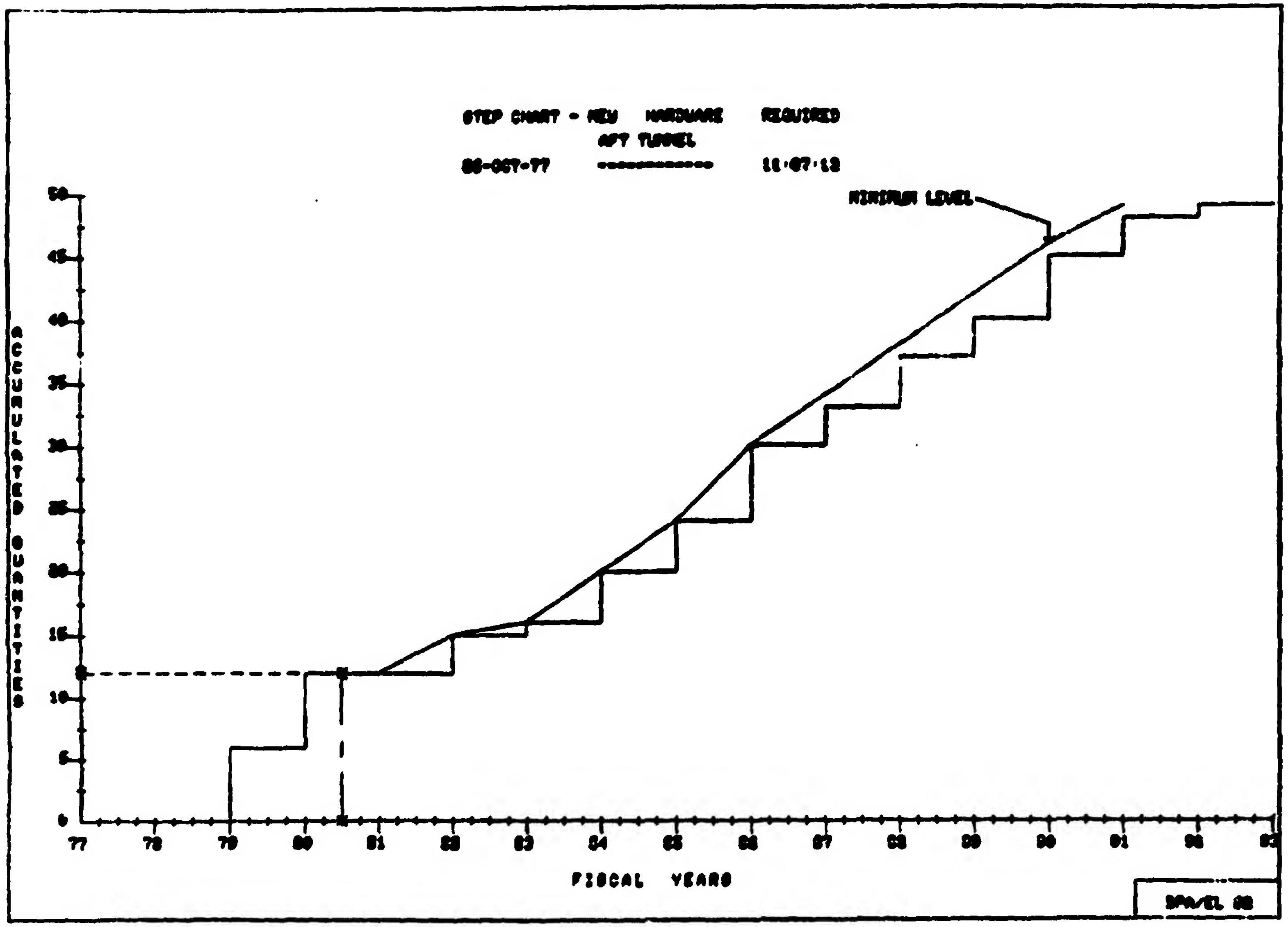


Figure 23. Step increases in hardware production.

C. Confidence of Meeting the Traffic Model

The nature of the BOSIM model is such that an unlimited supply of new hardware is effectively assumed to exist; however, new units are drawn and put into use only if a refurbished, previously used unit is not available. For each replication of the traffic model, the record of withdrawal of new units is interpreted as the "requirement" for new units to be available to sustain the launch schedule. The total number of new units required varies from replication to replication. The mean value of a group of replications (the sample mean) is simply called the "new hardware requirements." The number of replications required such that the sample mean is close to the population mean, to a certain confidence level, is an issue in all simulation models. It is believed that the mean value of 25 replications of BOSIM is within ±2 shipsets of the population mean at the 95 percent confidence level. The BOSIM new hardware requirements can also be regarded as the quantity of new hardware which gives a 50 percent confidence of making all launches on time with no launch delays resulting from lack of availability of hardware. Likewise, there is a 50 percent chance that at least one launch delay will occur if no more than the mean value of hardware is available.

The delivery schedule (or availability schedule) of the new hardware to support launches is crucial to the question of the confidence of making a particular launch. If all new hardware were available at the beginning of the traffic model, there would be virtual certainty for many years of making each launch. However, this implies a large early year cost. Delivering simply to meet the mean new hardware requirements is unacceptable because most launches then have a 50 percent chance of being delayed. Delivering hardware earlier than the mean requirement schedule increases the confidence of meeting each launch. From many studies of the early year funding constraints balanced with confidence in meeting the traffic model, the following groundrule evolved: Delivering hardware 1 year prior to the mean requirement date gives at least a 90 percent chance of making all launches on time and does not significantly increase early year funding. Reference 23 discusses SRB hardware demand probabilities and launch delays. Standard deviations for cumulative new unit requirements is discussed in Reference 24. The relation between production quantities, use philosophy and probability of meeting launch schedules is presented in Reference 25.

D. Hardware Flow Pipeline Size

Questions of pipeline size arise from a desire to know how much hardware is in the system at any time and where it is located in the flow. Of particular interest from a management standpoint is the number of extra units above the minimum need to sustain the launch rate and turnaround cycle. The minimum number needed is referred to as the number in process. The number in process plus the extra represents the

total available. An "extra" pool develops when hardware is delivered earlier than the mean requirement delivery rate demands. A representative complete history of hardware deliveries, requirements, lost, worn-out, in process, available and extra is shown in Table 19. The data in Table 19 show the following information:

1) Cumulative New Units Required — taken from the BOSIM "new units required ETR+WTR" line which has been passed through the running round off algorithm and then accumulated. DDT&E units are included.

2) Cumulative New Units Delivered — taken from ACP run, #460 delivery schedules which have been accumulated. DDT&E values have been added to the front to allow comparison with the requirements.

3) Cumulative Units Lost — taken from the BOSIM "mean total units lost by quarter" line which has been passed through the running round off algorithm and accumulated. Any DDT&E losses are included.

4) Cumulative Units Worn Out — taken from the BOSIM "mean worn out units" line which has been passed through the running round off algorithm and then accumulated.

5) Units Required "In Process" [A-(C+D)] — the "pipeline" which includes refurbished units which may be idle but does not include any new units which may be in storage.

6) Units Available [B-(C+D)] — the total number of units which are available including all new units which may be in storage.

7) Δ Between Available and In Process [F-E] — the number of units which are available in excess of the "in process" requirements.

Figure 24 shows lines (E) and (F) of Table 19 with the values plotted at the beginning of the quarter in all cases. Line (G) of Table 19 is represented by the gap between the two lines which are plotted in Figure 24. Additional subsystem data are presented in Reference 26.

E. Other Resource Schedules

In addition to new reusable hardware, there are many other types of resources that have a "schedule" in the sense that they are needed at a certain time. Hardware that is expended on each flight simply requires that a new one be available some time prior to every flight. Some work is essentially of a level-of-effort type and is relatively independent of traffic model. Refurbishment is accomplished on each piece of recovered, reusable hardware. Refurbishment schedules are an output of BOSIM. Figures 25, 26, and 27 demonstrate how they are analyzed by GRAH.

TABLE 19. AFT SKIRT POP-78-1-IV

	FY78				FY79			
	1	2	3	4	1	2	3	4
A) Cumulative New Units Required	0	0	0	2	4	6	8	10
B) Cumulative New Units Delivered	0	0	0	2	4	6	8	10
C) Cumulative Units Lost	0	0	0	0	0	0	1	1
D) Cumulative Units Worn Out	0	0	0	0	0	0	0	0
E) Units Required "In-Process" [A-(C+D)]	0	0	0	2	4	6	7	9
F) Units Available [B-(C+D)]	0	0	0	2	4	6	7	9
G) Δ Between Available and In-Process [F-E]	0	0	0	0	0	0	0	0

	FY80				FY81			
	1	2	3	4	1	2	3	4
A) Cumulative New Units Required	10	10	10	11	11	11	14	14
B) Cumulative New Units Delivered	10	10	10	11	11	11	14	16
C) Cumulative Units Lost	1	1	2	2	3	4	4	5
D) Cumulative Units Worn Out	0	0	0	0	0	0	0	0
E) Units Required "In-Process" [A-(C+D)]	9	9	8	9	8	7	10	9
F) Units Available [B-(C+D)]	9	9	8	9	8	7	10	11
G) Δ Between Available and In-Process [F-E]	0	0	0	0	0	0	0	2

	FY82				FY83			
	1	2	3	4	1	2	3	4
A) Cumulative New Units Required	16	19	20	22	26	29	32	35
B) Cumulative New Units Delivered	18	20	22	24	28	32	36	40
C) Cumulative Units Lost	6	7	8	9	11	12	14	17
D) Cumulative Units Worn Out	0	0	0	0		0	0	0
E) Units Required "In-Process" [A-(C+D)]	10	12	12	13	15	17	18	18
F) Units Available [B-(C+D)]	12	13	14	15	17	20	22	23
G) Δ Between Available and In-Process [F-E]	2	1	2	2	2	3	4	5

	FY84				FY85			
	1	2	3	4	1	2	3	4
A) Cumulative New Units Required	40	42	44	47	51	54	56	60
B) Cumulative New Units Delivered	44	48	52	56	60	64	68	72
C) Cumulative Units Lost	19	22	24	27	30	32	36	38
D) Cumulative Units Worn Out	0	0	0	0	0	0	0	0
E) Units Required "In Process" [A-(C+D)]	21	20	20	20	21	22	20	22
F) Units Available [B-(C+D)]	25	26	28	29	30	32	32	34
G) Δ Between Available and In Process [F-E]	4	6	8	9	9	10	12	12

	FY86				FY85			
	1	2	3	4	1	2	3	4
A) Cumulative New Units Required	64	67	70	74	76	79	83	87
B) Cumulative New Units Delivered	76	80	84	88	92	95	98	101
C) Cumulative Units Lost	41	44	48	51	53	57	59	62
D) Cumulative Units Worn Out	0	0	0	0	1	1	1	1
E) Units Required "In-Process" [A-(C+D)]	23	23	22	23	22	21	23	24
F) Units Available [B-(C+D)]	35	36	36	37	38	37	38	38
G) Δ Between Available and In-Process [F-E]	12	13	14	14	16	16	15	14

TABLE 19. (Concluded)

	FY88 1	FY88 2	FY88 3	FY88 4	FY89 1	FY89 2	FY89 3	FY89 4
A) Cumulative New Units Required	91	94	97	99	102	106	110	113
B) Cumulative New Units Delivered	104	107	110	113	116	119	122	125
C) Cumulative Units Lost	66	69	72	76	79	82	86	89
D) Cumulative Units Worn Out	1	1	1	1	1	1	1	1
E) Units Required "In-Process" [A-(C+D)]	24	24	24	22	22	23	23	23
F) Units Available [B-(C+D)]	37	37	37	36	36	36	35	35
G) Δ Between Available and In-Process [F-E]	13	13	13	14	14	13	12	12

	FY90 1	FY90 2	FY90 3	FY90 4	FY91 1	FY91 2	FY91 3	FY91 4
A) Cumulative New Units Required	116	121	124	127	130	134	136	136
B) Cumulative New Units Delivered	128	131	134	136	136	136	136	136
C) Cumulative Units Lost	93	96	100	104	107	111	114	118
D) Cumulative Units Worn Out	1	1	1	1	1	1	1	1
E) Units Required "In-Process" [A-(C+D)]	22	24	23	22	22	22	21	17
F) Units Available [B-(C+D)]	34	34	33	31	28	24	21	17
G) Δ Between Available and In-Process [F-E]	12	10	10	9	5	2	0	0

	FY92 1	FY92 2	FY92 3	FY92 4	FY93 1	FY93 2	FY93 3	FY93 4
A) Cumulative New Units Required	136	136	136	136				
B) Cumulative New Units Delivered	136	136	136	136				
C) Cumulative Units Lost	120	120	120	120				
D) Cumulative Units Worn Out	1	1	1	1				
E) Units Required "In-Process" [A-(C+D)]	15	15	15	15				
F) Units Available [B-(C+D)]	15	15	15	15				
G) Δ Between Available and In-Process [F-E]	0	0	0	0				

IV. COST PARAMETERS

A project as complex as the SRB (12-year duration, 500 flights and an approximate $6 billion run-out cost) involves many cost parameters. NASA made a commitment to the Congress in 1971$ that an SRB could be developed which could operate on a recurring basis for $3.28 million per flight. Status estimates of CPF are regularly made against this commitment to assess the progress of the SRB development effort. From a hardware standpoint, the quantities of subsystems vary from a few dozen to several hundred. This leads to a TFU cost and learning curve approach to predict unit cost. Most CPF studies center on predictions for the operational shuttle flights (from Flight 7 to approximately 500). The hardware for these operational flights is expected to be essentially identical to the hardware used for the first 6 DDT&E flights. Thus the DDT&E experience cost data base is used for operational flight cost predictions. The reusable feature of the SRB design means that many early operational flights can be accomplished using recovered and

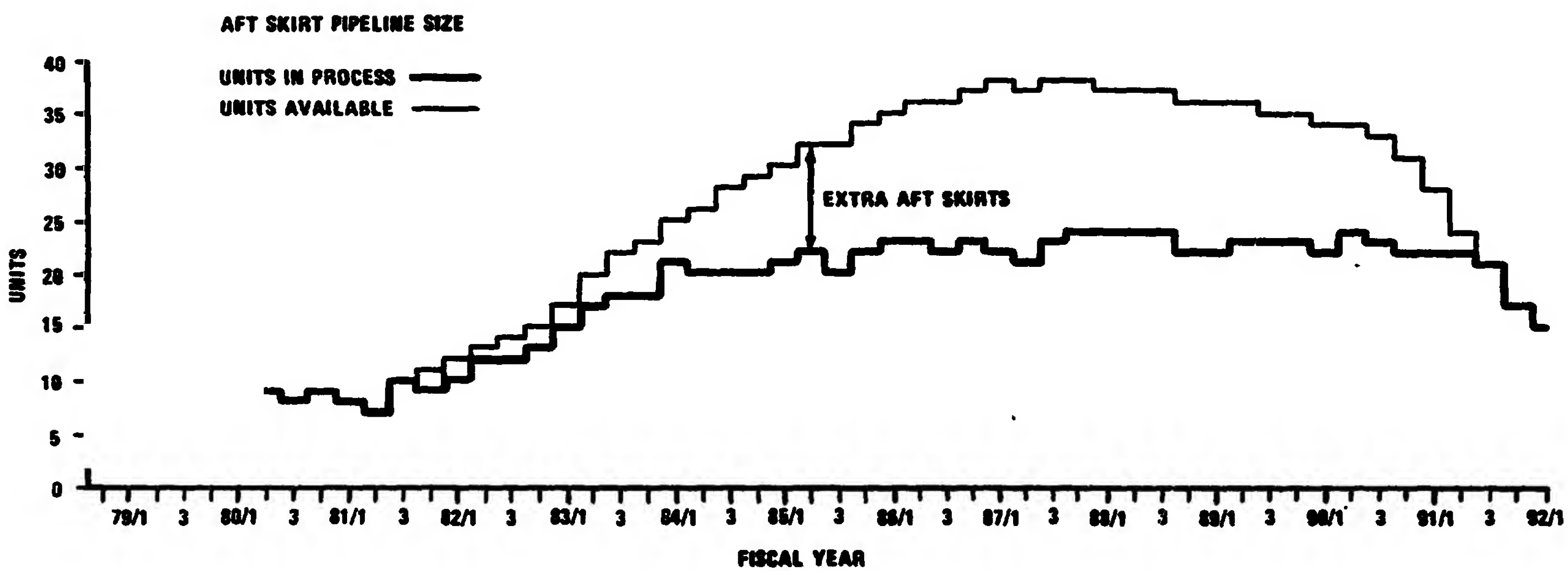


Figure 24. Aft skirt pipeline size.

REFURB. HARDWARE REQUIREMENTS

SUBSYSTEM	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
PER YEAR — FWD CYLINDER	0	0	0	4	40	65	129	202	231	235	230	230	218	0	0
CUMULATIVE — FWD CYLINDER	0	0	0	4	44	109	238	440	671	906	1136	1366	1584	1584	1584

HARDWARE REQUIREMENTS -- PRESENTED IN QUARTERS

FWD CYLINDER

	FY 77				FY 78				FY 79				FY 80				FY 81		
0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	10	10	10	10

	FY 82				FY 83				FY 84				FY 85				FY 86		
16	16	16	17	32	32	32	33	50	50	51	51	57	58	58	58	58	59	59	59

	FY 87				FY 88				FY 89				FY 90				FY 91		
57	57	58	58	57	57	58	58	54	54	55	55	0	0	0	0	0	0	0	0

Figure 25. Example of refurbishment hardware requirements for forward cylinder.

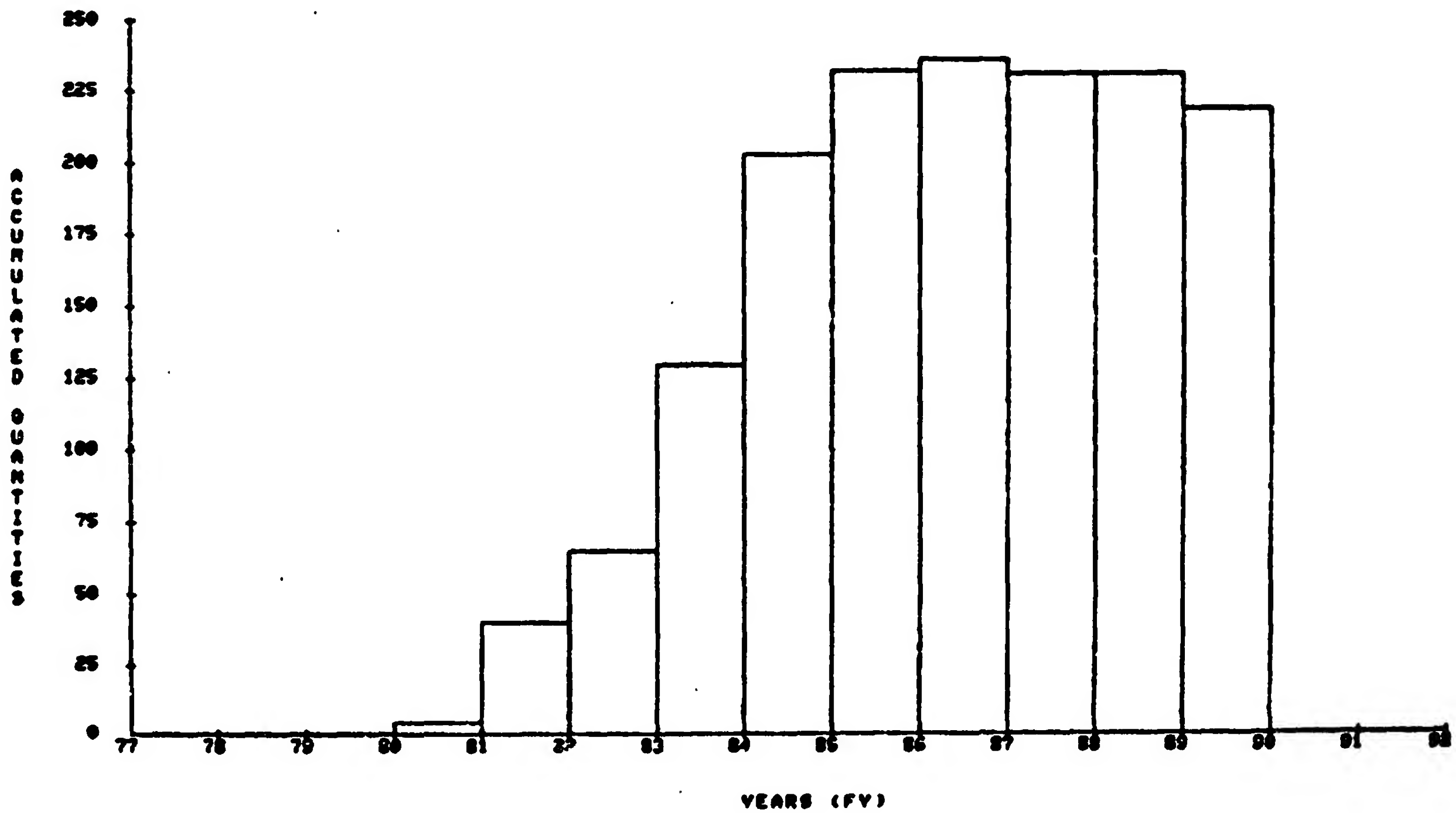


Figure 26. Bar graph of refurbishment requirements for forward cylinder.

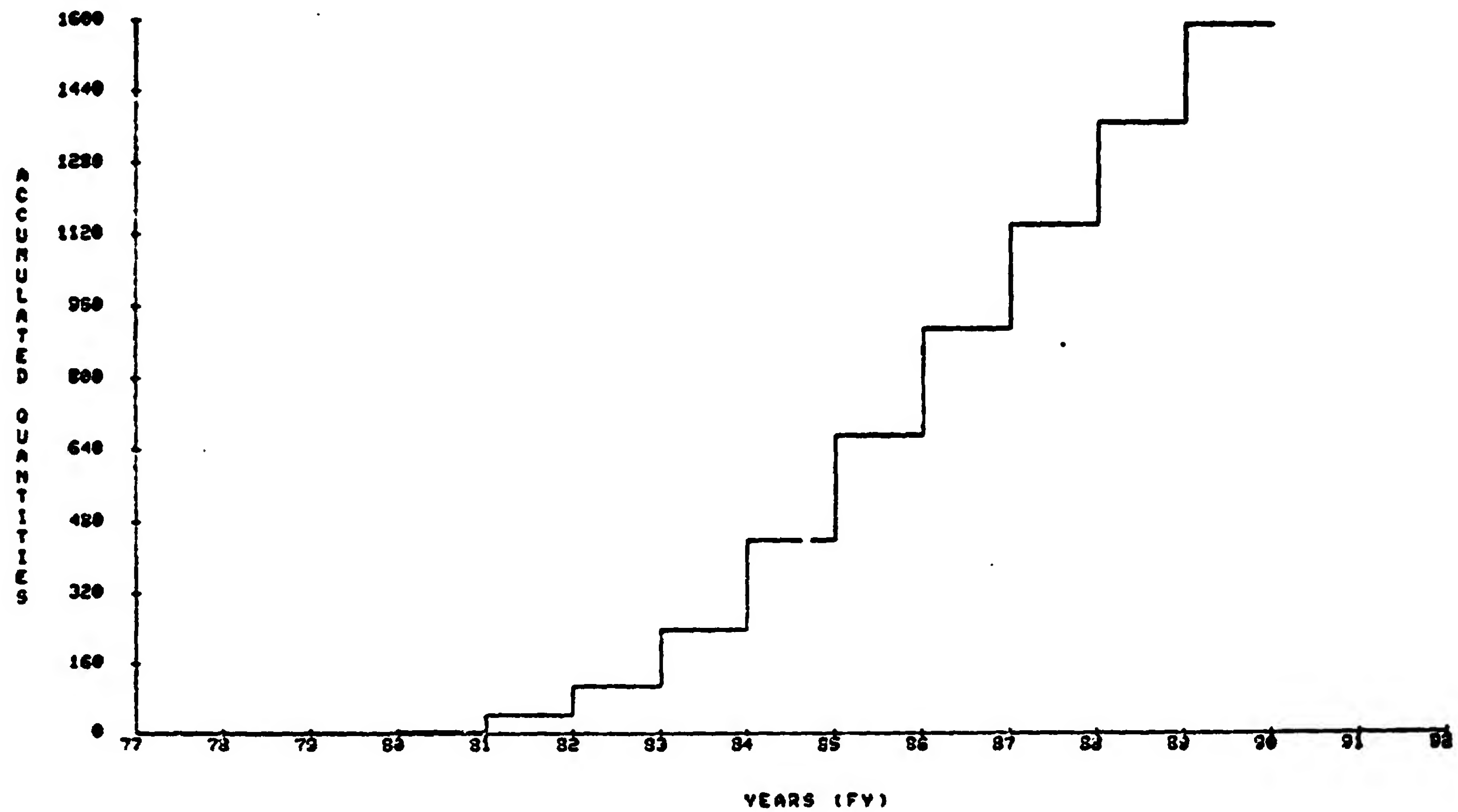


Figure 27. Plot graph of cumulative refurbishment requirements for forward cylinder.

refurbished DDT&E flight hardware. Hence a production gap develops between the conclusion of manufacture for the first six flights and the resumption of production to support later operational flights. Special costing assumptions are needed to determine the cost penalty resulting from this break in production.

A. TFU Cost

Approximately 12 sets of SRB hardware are being manufactured in the DDT&E program; i.e., enough for each of the six DDT&E flights to be performed with new hardware (two SRB's are required per flight). The cost to manufacture the first flight set is determined through consultation with project office personnel and the various businesses presently under contract. This process establishes the TFU cost for each component. Figures 28 and 29 show representative TFU's used in a recent budget exercise. The TFU cost concept is also applied to the refurbishment operation as is demonstrated in Figures 28 and 29.

B. Learning Curves

The learning curve theory states that as units on a production line are produced, the time, and subsequently the cost, to produce them decreases. The learning curve is used in the cost analysis to represent uninterrupted production line cost decreases. For the purpose of this document, the term learning curve and cost improvement curve are interchangeable and will pertain to dollars and units.

In the cost analysis program, both the Wright learning curve and the Crawford learning curve methods are available. The Crawford learning curve method is based on the theory that each time the total quantity of units produced is doubled, the cost to produce the last unit of this doubled quantity will be reduced by a constant percentage.

The Wright learning curve method is based on the theory that each time the production of a product doubles, the new cumulative average cost declines by a constant percentage. In both cases, the complement of this constant percentage of reduction is commonly referred to as the "slope." This means that if the constant percentage of reduction is 20 percent, the slope would be 80 percent (100 percent less 20 percent).

The slope or constant relationship between cost and unit is determined from the equation:

$$2^B = \text{learning curve} \qquad (1)$$

SUBSYSTEM	THEORETICAL FIRST UNIT COST (TFU)		COST IMPROVEMENT CURVE	
	NEW BUY	REFURB	NEW BUY	REFURB
BAC TVC				
TVC NEW	7534.60	NA	NA	NA
SUB RECOVERY				
PILOT CHUTE	1.15	NA	92.0	NA
DROGOGUE CHUTE	44.56	NA	92.0	NA
MAIN CHUTE	83.61	NA	92.0	NA
PARA LOC AID	16.72	1.68	92.0	90.0
MCHT SUPT STRUC	70.55	NA	98.0	NA
SUB TVC				
ACTUATOR	179.97	10.39	90.0	85.0
POWER SUPPLY	436.25	25.22	90.0	85.0
SUB STRUCTURES				
NOSE CAP	31.32	NA	92.0W	NA
NOSE FRUSTUM	349.38	44.54	86.0W	85.0
SEPARATION RING	36.52	NA	86.0W	NA
FWD SKIRT	408.59	70.93	87.0W	8[illegible]
FWD TUNNEL	27.86	1.5[illegible]	88.0W	8[illegible]
AFT TUNNEL	18.36	0.84	[illegible].0W	85.0
REUSABLE STRUTS	67.29	2.89	95.0W	85.0
EXPNDBL STRUTS	67.28	NA	95.0W	NA
ET ATTACH RING	143.92	3.40	91.0W	85.0
AFT SKIRT	1042.12	104.12	87.0W	85.0
THERMAL SHIELD	20.42	NA	93.0W	NA
SUB E+I				
INTEGR ELEC ASMBL	480.99	62.73	92.0	85.0
ALTITUDE SWITH	6.56	1.08	90.0	85.0
FRUSTUM LOCAT AID	18.37	1.72	90.0	85.0
RF BEACON	5.25	0.56	90.0	85.0
RF BEACON ANTENNA	0.27	0.04	90.0	85.0
FLASHING LIGHT	1.97	0.22	90.0	85.0
RATE GYRO	45.70	4.38	90.0	85.0
CABLE-REUSABLE	52.50	9.25	90.0	85.0
SENSORS	2.88	0.26	90.0	85.0
RECOVERY BATTERY	4.48	NA	85.0	NA
FRUSTUM BATTERY	1.49	NA	85.0	NA
CABLE-THROWAY	11.93	NA	85.0	NA
SUB SEP MOTORS				
SEPARATION MOTORS	5.35	NA	95.0	NA
SUB PYROTECHNICS				
PYROTECHNICS	46.50	NA	100.0	NA

Figure 28. Subsystem hardware cost data - FY76/1 K$.

SUBSYSTEM	THEORETICAL FIRST UNIT COST (TFU)		COST IMPROVEMENT CURVE	
	NEW BUY	REFURB	NEW BUY	REFURB
TM1				
MANAGEMENT	16.22	NA	100.0	NA
TM2				
PRJCT ENG+INTGR	19.06	NA	100.0	NA
TM3				
SPRT EQPT+TOOL	12.39	NA	100.0	NA
TM4				
PLAN+DIR,TECH SPT	55.63	NA	100.0	NA
LABOR, CASE	19.21	NA	85.0	NA
AFT CYL, CASE	186.24	NA	96.0	NA
FWD CYL, CASE	135.45	NA	96.0	NA
AFT STIF TEE,CASE	9.99	NA	96.0	NA
CYL, OTH SEG,CASE	126.99	NA	96.0	NA
FWD,OTH SEG,CASE	220.11	NA	96.0	NA
ATCH,OTH SEG,CASE	186.24	NA	96.0	NA
AFT,OTH SEG,CASE	243.17	NA	96.0	NA
JT HRD,SEG,CASE	20.32	NA	100.0	NA
REFURB, CASE	76.0[illegible]	NA	9[illegible].0	NA
LABOR, NOZ	446.06	NA	98.0	NA
ELASTOMER,NOZ	53.28	NA	95.0	NA
BEARING SHIMS,NOZ	117.33	NA	95.0	NA
AFT END RING,NOZ	55.07	NA	95.0	NA
FWD END RING,NOZ	55.8[illegible]	NA	95.0	NA
COMP RING, NOZ	44.87	NA	95.0	NA
OTH PRTS, NOZ	191.2[illegible]	NA	95.0	NA
REFURB, NOZZLE	10.55	NA	94.0	NA
LABOR, IGNITER	12.7[illegible]	NA	96.0	NA
MET PRTS,IGNITER	15.15	NA	90.3	NA
REFURB, IGNITER	4.25	NA	97.3	NA
LAB+MAT,PROPELNT	793.22	NA	99.3	NA
LAB+MAT,INSLINER	125.05	NA	94.4	NA
LABOR,ELECTRICAL	16.95	NA	93.0	NA
LAB+MAT,OTH FIN	126.98	NA	96.0	NA
MISC MATERIALS	3.7[illegible]	NA	10[illegible]	NA
TM5				
MULTI ELEM SUPPORT	68.69	NA	10[illegible]	NA

Figure 29. Subsystem hardware cost data - FY76/1 K$.

where

$$B = \text{slope} = \frac{\log\ (\text{learning curve})}{\log\ (2)} \quad . \tag{2}$$

For the Crawford cost method, the individual unit cost is determined from the function·

$$\text{Unit Cost} = TFU*X^B \quad , \tag{3}$$

where TFU is the theoretical first unit cost, X is the unit number being costed, and B is the slope.

For the Wright cost method, the cumulative average cost of a number of units is determined by the function:

$$\text{Cumulative Average Cost} = TFU*X^B \tag{4}$$

from which the individual unit cost is determined as:

$$\text{Unit Cost} = TFU*(X^{B+1} - (X-1)^{B+1}),\ X > 1 \quad . \tag{5}$$

The learning curve is usually plotted on log-log paper; however, when it is plotted on ordinary square graph paper, the true "curve" is revealed. Figure 30 illustrates a plot, on ordinary square graph paper, of the individual unit costs for both types of learning curves each having a slope of 80 percent, with a first unit cost of $100.00. Note that Wright learning is faster than Crawford learning. Figure 31 is a graphic representation of the unit cost data presented in Figure 30, except that it is plotted on log-log paper. Where learning experience is not applicable (learning curve input parameter is 0), the analysis assumes the first unit cost is essentially a predetermined constant cost per unit.

For elements costed along the learning curve, the total cost of the element is determined by summing the individual unit cost as computed either by equation (3) or by equation (5). The cost of a spare unit is determined by computing for each phase (development and operational), the average unit cost of the new hardware units (new and spares) costed for that phase. This average unit cost is the cost of a spare unit. Hardware costing of new and spare units, along the learning curve is illustrated in Figure 32. Figures 28 and 29 show the learning curves assumed. All are Crawford unless a "W" appears indic Wright.

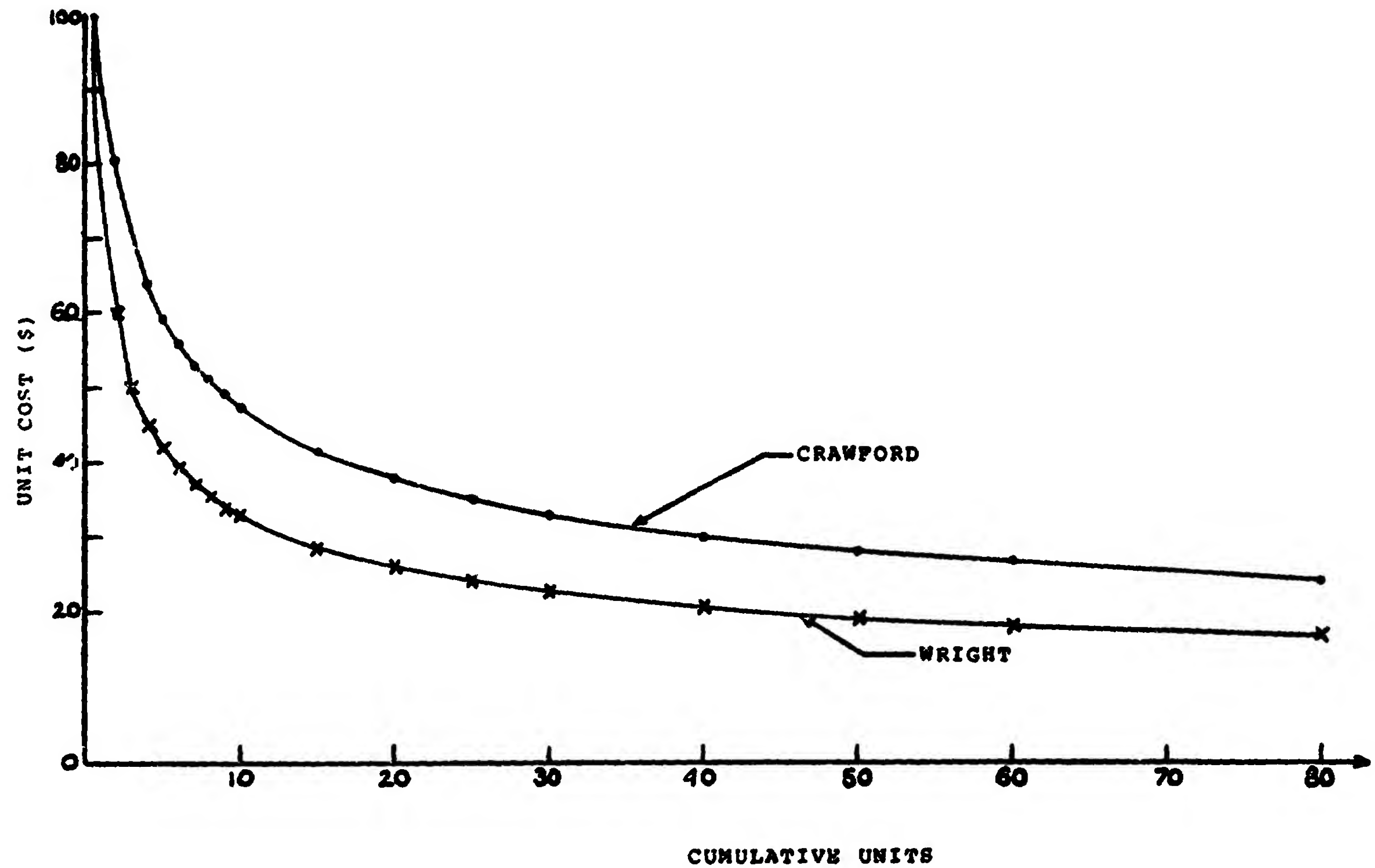


Figure 30. Unit cost, Crawford versus Wright (80 percent curve).

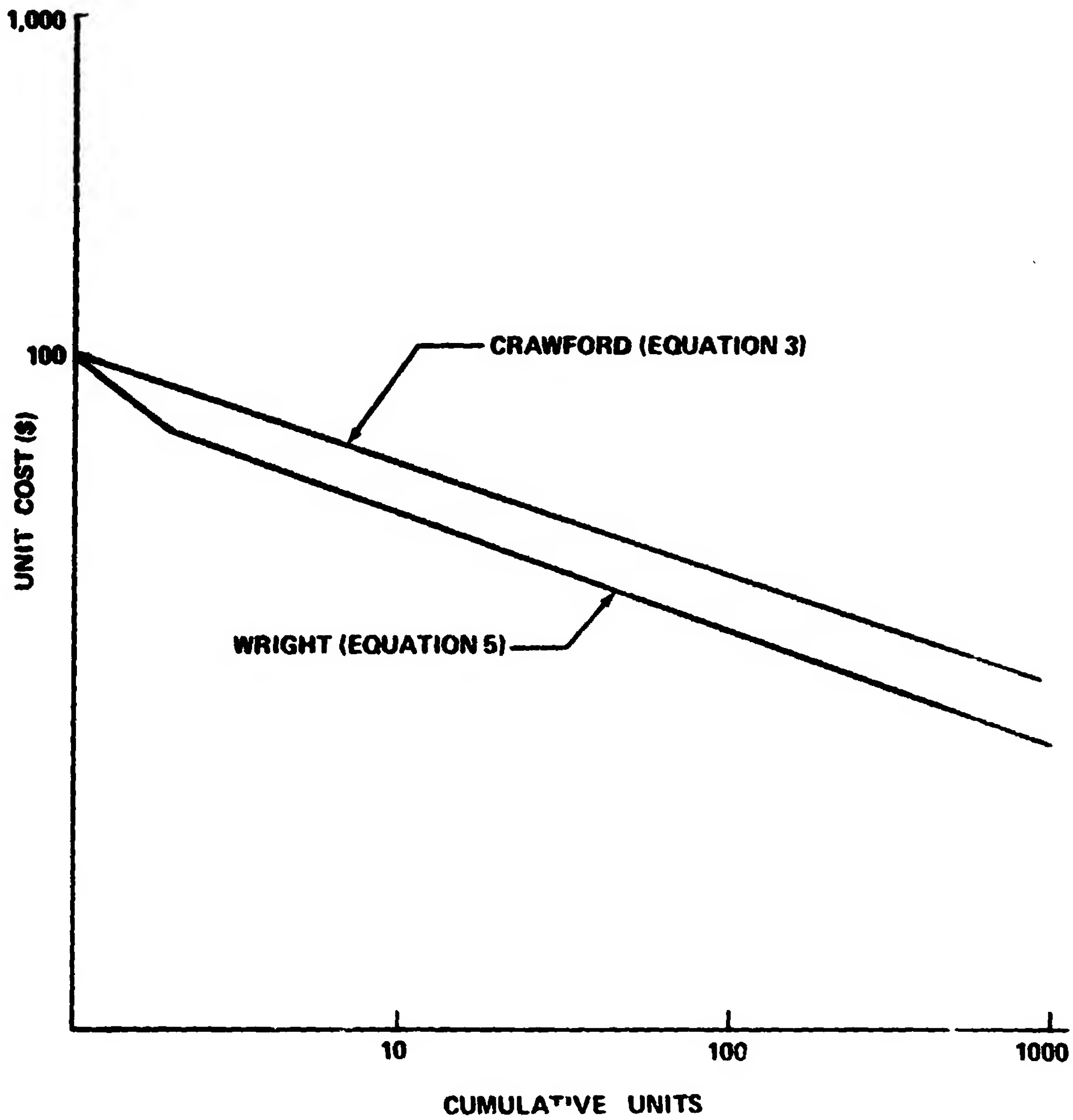
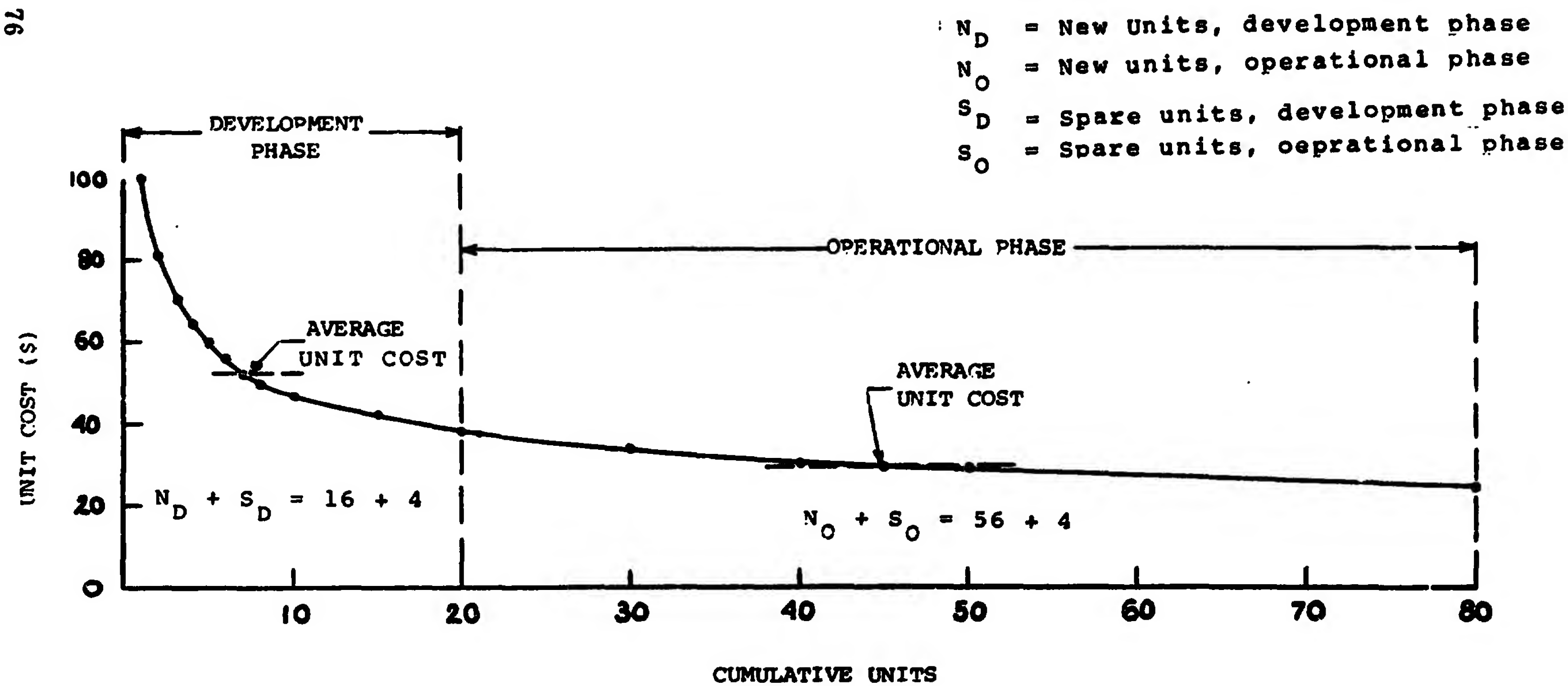


Figure 31. Unit cost. Crawford versus Wright (80 percent curve).



Per Phase:

Total Cost (Spares) = Average Unit Cost * Number of Spare Units

Total Cost (New) = Total Cost (New +Spares) - Total Cost (Spares)

Figure 32. Costing of new units.

C. Production Gap

Determining the cost effects of production interruptions should consider the following elements:

1) Quantity produced to date

2) Time lapse between lots

3) Availability of the same personnel

4) Condition and availability of proven tools and jigs

5) Similarity of layout and space allocation.

Unfortunately, this type of empirical data is not yet available for the SRB. Currently only estimates of their combined effects can be made. However, as the Space Shuttle program progresses, empirical data will become available and costing techniques can be modified to more accurately predict costs.

The general situation is that having produced 12 SRB's in DDT&E, what do we expect number 13 to cost when there has been a delay of from 1 to 2 years? It is reasonable to assume that the same contractor who built No. 12 will build No. 13. Surely, the thirteenth would not cost as much as the first and as surely it would not cost what 13 would have cost with no production break. A percent loss of learning parameter is defined such that 100 percent loss means we are back to the TFU and 0 percent means there was essentially smooth production. A factor of 50 percent is normally assumed for budget exercises.

The method of analysis uses a "one-half" production gap penalty (PGP) algorithm to estimate the cost increase due to the production interruption. The "one-half" PGP algorithm determines the unit number on the learning curve which yields a cost equal to the average of the TFU cost and the cost of the first operational unit. For the Crawford learning curve, the cost of unit X, C (X) is found by

$$C(X) = TX^{B} \tag{6}$$

where T is the TFU and

$$B = \frac{\log L}{\log 2} \tag{7}$$

where L is the learning curve slope.

Once the penalty cost, C(P), has been determined, the unit number P is computed by

$$P = 10 \exp \frac{\log C(P) - \log T}{B} . \qquad (8)$$

The fractional value is truncated to yield a worst-case approximation.

The Wright learning curve requires a different method of calculation. The cost of unit X, C(X), is found by

$$C(X) = T(X^{B+1} - (X-1)^{B+1}) \qquad (9)$$

where T and B are defined as in equation (6).

When given C(X), T and B, X can be found by finding the solution to

$$F(X) = 0 = X^{B+1} - (X-1)^{B+1} - \frac{C(X)}{T} , \qquad (10)$$

which is algebraically equivalent to equation (9). Table 20 presents the data relevant to the production gap penalty inputs for SRM and SRB subsystems.

Figure 33 presents cost/unit plots for two subsystems using the Crawford learning curve, the SRM case labor (85 percent), and the SRM case aft cylinder (96 percent).

Lines A and D are the graphs of the learning curve without interruption of production. Curves B and E are graphs of the cost/unit using the one-half production gap penalty units. Curves C and F are the graphs of cost/unit for a full production gap penalty, that is, the cost of the first operational unit is the original TFU and learning begins again at the original rate. Figure 34 presents a plot of the cumulative average cost/unit for the ET Attach Struts Reusable and the Nose Frustum subsystems which use a Wright Learning curve (95- and 86-percent slopes, respectively). The cumulative average cost/unit is used because it is the parameter on which the cost decrease is based. Curves A, B, C, D, E, and F are the same type as those presented in Figure 33.

TABLE 20. ONE-HALF PRODUCTION GAP PENALTY UNIT NUMBERS

SUBSYSTEM	LEARNING CURVE VALUE	DDT&E UNITS REQUIRED	FIRST OPERATIONAL UNIT NUMBER	UNIT NUMBER TO ACHIEVE A 1/2 PRODUCTION GAP PENALTY
SRM				
Labor, Case	85	12	13	2
Aft Cyl, Case	96	12	13	3
Fwd Cyl, Case	96	12	13	3
Aft Stif Tee, Case	96	18	19	3
Cyl, Oth Seg, Case	96	26	27	4
Fwd, Oth Seg, Case	96	6	7	2
Atch, Oth Seg, Case	96	6	7	2
Aft, Oth Seg, Case	96	6	7	2
Refurb, Case	90	6	7	2
Labor, Noz	98	12	13	3
Comp Ring, Noz	95	7	8	2
Oth Prts, Noz	95	7	8	2
Elastomer, Noz	95	12	13	3
Bearing Shims, Noz	95	12	13	3
Aft End Ring, Noz	95	12	13	3
Fwd End Ring, Noz	95	12	13	3
Refurb, Nozzle	90	3	4	1
Labor, Igniter	96	13	14	3
Met Prts, Igniter	96	8	9	2
Refurb, Igniter	90	7	8	2
Lab & Mat, Propellant	99	12	13	3
Lab & Mat, Ins & Liner	94	12	13	3
Labor, Electrical	93	12	13	3
Lab & Mat, Mtr Fin	96	12	13	3
SRB				
E&I				
Fwd Skrt Compnts	92	12	13	3
IEAS	92	12	13	3
Recovery Battery	92	12	13	3
Frustum Components	92	12	13	3
Fwd Cables	92	12	13	3
Aft Cables	92	12	13	3
TVC				
Actuator	90	24	25	4
Power Supply	90	24	25	4

TABLE 20. (Concluded)

SUBSYSTEM		LEARNING CURVE VALUE	DDT&E UNITS REQUIRED	FIRST OPERATIONAL UNIT NUMBER	UNIT NUMBER TO ACHIEVE A 1/2 PRODUCTION GAP PENALTY
Structures					
Nose Cap	W*	92	12	13	2
Nose Frustum	W	86	12	13	2
Separation Ring	W	86	12	13	2
Fwd Skirt	W	87	12	13	2
Sys Tunnel Fwd	W	88	12	13	2
Sys Tunnel Aft	W	88	12	13	2
ET Attach Ring	W	91	12	13	2
ET Attach Struts Reusable	W	95	12	13	2
ET Attach Struts Expendable	W	95	24	25	3
Aft Skirt	W	87	12	13	2
Thermal Shield	W	90	12	13	2
RECOVERY					
Pilot Chute		95	12	13	3
Drogue Chute		95	12	13	3
Main Chute		95	36	37	5
Satellite Floats		95	36	37	5
SEPARATION					
Separation Mtrs		95	96	97	8
PYROTECHNICS					
Pyrotechnics		95	12	13	3

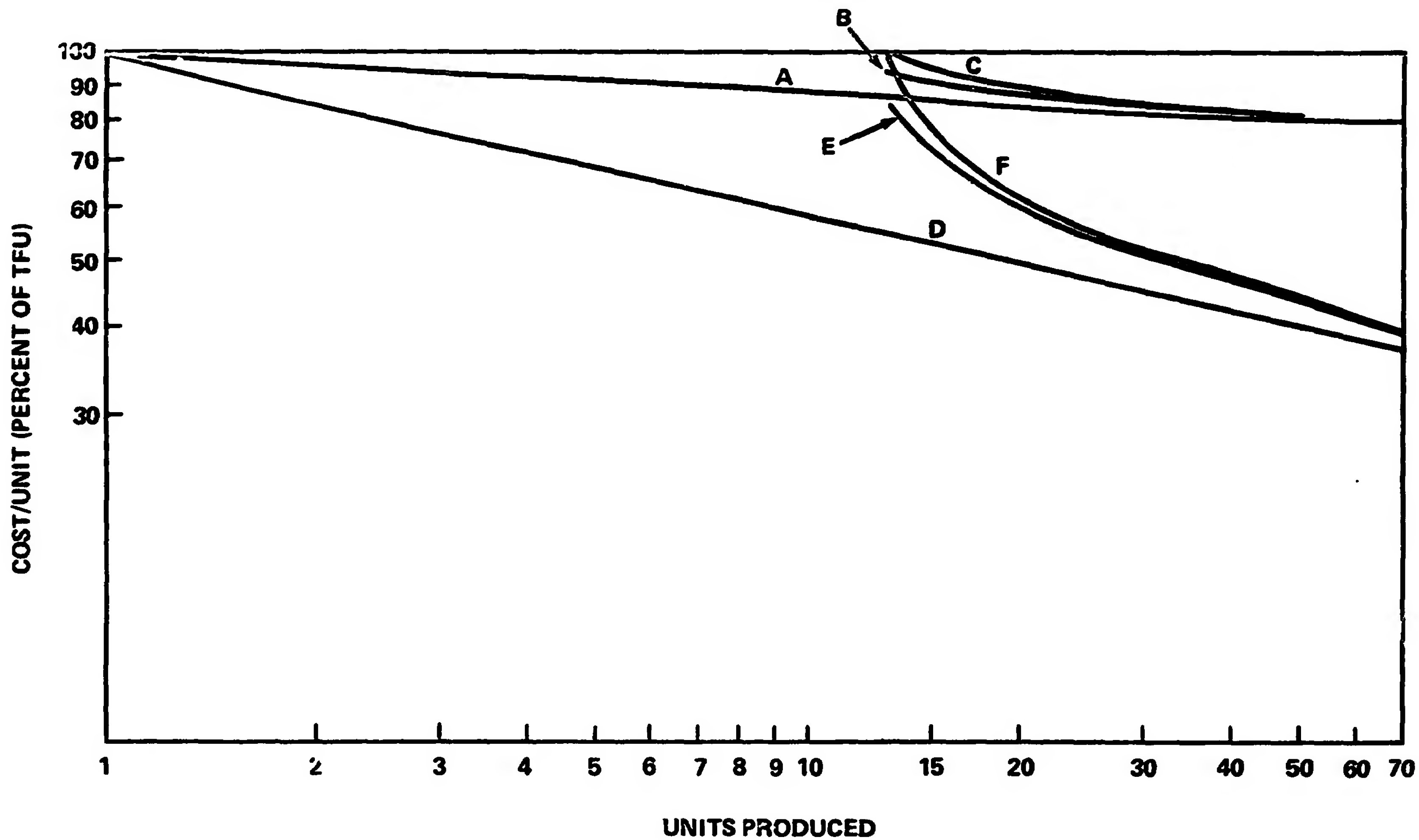


Figure 33. Examples of Crawford learning curves.

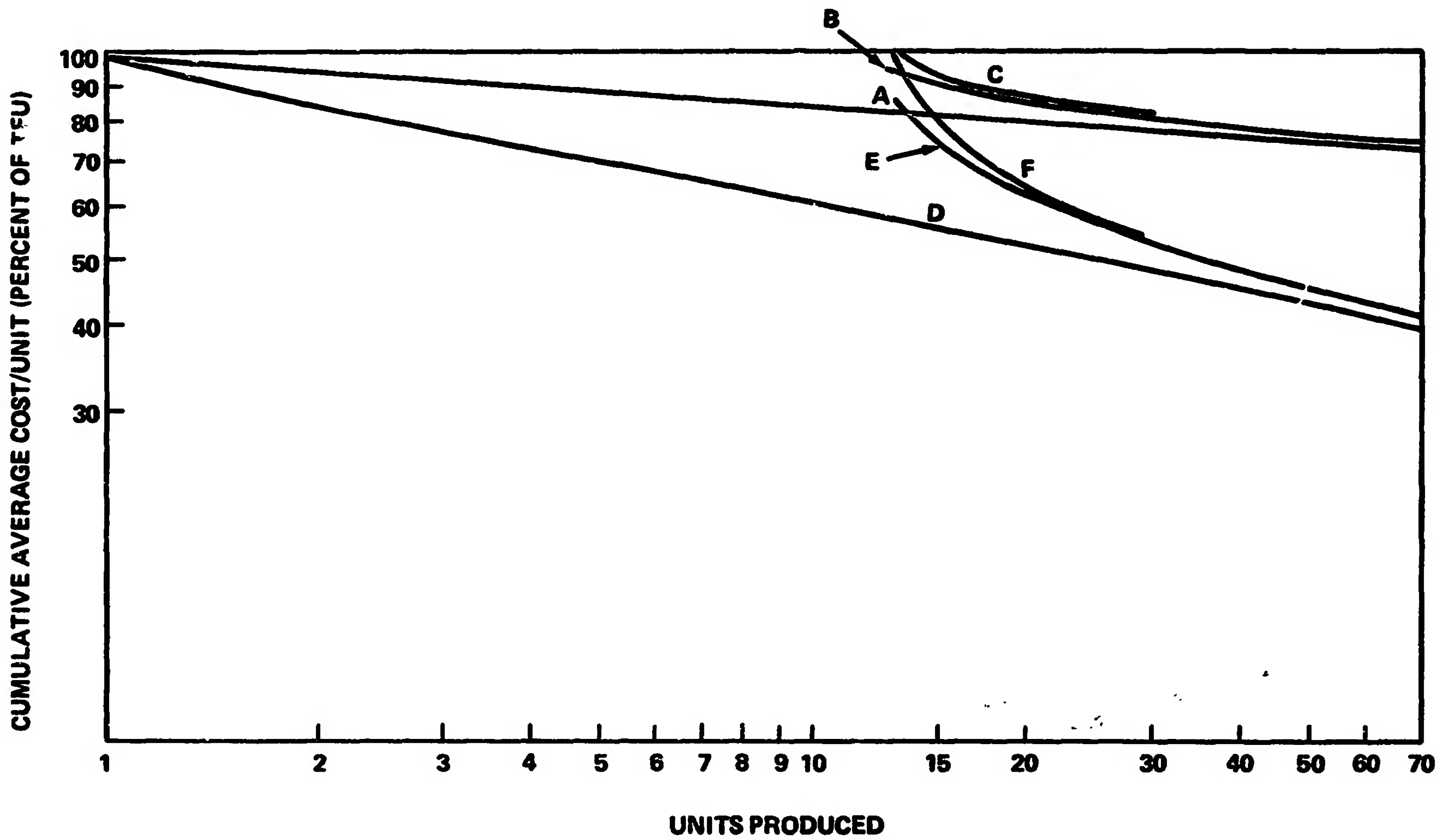


Figure 34. Examples of Wright learning curves.

Figures 33 and 34 compare favorably with Exhibit XI-1 on Page 372 of Reference 27. If the cost of the first operational unit (unit number 13 for both cases) is plotted above the penalty unit number, then the straight lines A and D are redrawn. When using linear axes, a shift of either axis results in the same graph, as the relationship between axes is constant. However, when using a log-log grid, a shift in either axis disrupts the relationship of the axes, which is why Curves B, C, E, and F in Figures 33 and 34 are not linear.

A review of the production gap problem is presented in Reference 28.

D. Inflation

Input cost data may be declared in dollars of any fiscal year and quarter from FY72/3 through FY92/4 and are assumed (by the analysis) to be at the end of that year and quarter. To provide results in a constant or standardized base year dollar of interest, the CPF inflation routine deflates or inflates the input cost data. The inflation rates currently modeled in the program are listed in Tables 21 and 22. The tables are updated to reflect actual inflation rates experienced as time progresses. Table 21 is the standard NASA inflation. Table 22 reflects actual historical experience of the Thiokol Corporation and is therefore used for Solid Rocket Motor costs.

The calendar and fiscal year relationships are provided with a quarterly breakdown of each. The inflation rates are in percent per quarter. The cumulative inflation factor is the conversion factor that changes dollars from one base year to another to account for the inflation, and has been computed to include a compounded inflation rate effect.

E. CPF Computer Program

The hardware quantity results from the logistics simulation together with such non-hardware costs as transportation, assembly, sustaining engineering, etc. form the basis of a total operational flights cost analysis. In addition to the TFU and learning curve costing method, other cost analysis techniques such as cost/year or cost/service operation are used to [illegible] the remaining Shuttle program elements which are considered chargeable to SRB operations cost. Dividing the total operations cost in constant year dollars by the appropriate number of flights determines the average recurring CPF which can be compared to the Agency commitment to Congress.

The computer program designed to calculate average recurring CPF is called the CPF program. A brief description and flow chart is presented in Appendix D. The program is fully documented in References 29 and [illegible] The input data required and typical output are represented by Figures 3[illegible] through 44.

TABLE 21. STANDARD NAS INFLATION

QTR	CALENDER YR/QTR	FISCAL YR/QTR	INFLATION RATE	CUMULATIVE INFLATION
1	72/1	72/3	1.250	1.00000
2	72/2	72/4	1.250	1.01250
3	72/3	73/1	1.250	1.02516
4	72/4	73/2	1.250	1.03797
5	73/1	73/3	1.250	1.05095
6	73/2	73/4	1.250	1.06408
7	73/3	74/1	1.250	1.07738
8	73/4	74/2	1.250	1.09085
9	74/1	74/3	3.750	1.10449
10	74/2	74/4	3.750	1.14590
11	74/3	75/1	3.750	1.18888
12	74/4	75/2	3.750	1.23346
13	75/1	75/3	1.750	1.27971
14	75/2	75/4	1.750	1.30211
15	75/3	76/1	1.750	1.32489
16	75/4	76/2	1.750	1.34808
17	76/1	76/3	1.750	1.37167
18	76/2	76/4	1.750	1.39568
19	76/3	76/5	1.750	1.42010
20	76//	77/1	1.750	1.44495
21	77/1	77/2	1.750	[illegible]324
22	77/2	77/3	1.750	[illegible]567
23	77/3	77/4	1.750	1.[illegible]2215
24	77/4	78/1	1.750	1.54879
25	78/1	78/2	1.750	1.57589
26	78/2	78/3	1.750	1.60347
27	78/3	78/4	1.750	1.63153
28	78/4	79/1	1.7[illegible]	1.66008
29	79/1	79/2	1.750	1.68913
30	79/2	79/3	1.750	1.71869
31	79/3	79/4	1.750	1.74877
32	79/4	80/1	1.750	1.77937
33	80/1	80/2	1.750	1.81051
34	80/2	80/3	1.750	1.84219
35	80/3	80/4	1.750	1.87443
36	80/4	81/1	1.750	1.90723
37	81/1	81/2	1.750	1.94061
38	81/2	81/3	1.750	1.97457
39	81/3	81/4	1.750	2.00913
40	81/4	82/1	1.750	2.04429
41	82/1	82/2	1.750	2.08006
42	82/2	82/3	1.750	2.11646
43	82/3	82/4	1.750	2.15350
44	82/4	83/1	1.750	2.19119
45	83/1	83/2	1.750	2.22953
46	83/2	83/3	1.750	2.26855
47	83/3	83/4	1.750	2.30825
48	83/4	84/1	1.750	2.34864
49	84/1	84/2	1.750	2.38974
50	84/2	84/3	1.750	2.43157
51	84/3	84/4	1.750	2.47412
52	84/4	85/1	1.750	2.51741

TABLE 21. (Concluded)

QTR	CALENDER YR/QTR	FISCAL YR/QTR	INFLATION RATE	CUMULATIVE INFLATION
53	85/1	85/2	1.750	2.56147
54	85/2	85/3	1.750	2.60630
55	85/3	85/4	1.750	2.65191
56	85/4	86/1	1.750	2.69831
57	86/1	86/2	1.750	2.74553
58	86/2	86/3	1.750	2.79358
59	86/3	86/4	1.750	2.84247
60	86/4	87/1	1.750	2.89221
61	87/1	87/2	1.750	2.94283
62	87/2	87/3	1.750	2.99433
63	87/3	87/4	1.750	3.04673
64	87/4	88/1	1.750	3.10004
65	88/1	88/2	1.750	3.15429
66	88/2	88/3	1.750	3.20949
67	88/3	88/4	1.750	3.26565
68	88/4	89/1	1.750	3.32281
69	89/1	89/2	1.750	3.38096
70	89/2	89/3	1.750	3.44013
71	89/3	89/4	1.750	3.50033
72	89/4	90/1	1.750	3.56158
73	90/1	90/2	1.750	3.62391
74	90/2	90/3	1.750	3.68733
75	90/3	90/4	1.750	3.75185
76	90/4	91/1	1.750	3.81752
77	91/1	91/2	1.750	3.88432
78	91/2	91/3	1.750	3.95230
79	91/3	91/4	1.750	4.02146
80	91/4	92/1	1.750	4.09184
81	92/1	92/2	1.750	4.16344
82	92/2	92/3	1.750	4.23631
83	92/3	92/4	1.750	4.31044

TABLE 22. THIOKOL INFLATION

QTR	CALENDER YR/QTR	FISCAL YR/QTR	INFLATION RATE	CUMULATIVE INFLATION
1	72/1	72/3	.855	1.00000
2	72/2	72/4	.855	1.00855
3	72/3	73/1	.855	1.01717
4	72/4	73/2	.855	1.02587
5	73/1	73/3	1.697	1.03464
6	73/2	73/4	1.697	1.05220
7	73/3	74/1	1.697	1.07007
8	73/4	74/2	1.697	1.08823
9	74/1	74/3	5.540	1.10670
10	74/2	74/4	5.540	1.16801
11	74/3	75/1	5.540	1.23272
12	74/4	75/2	5.540	1.30101
13	75/1	75/3	2.877	1.37309
14	75/2	75/4	2.877	1.41260
15	75/3	76/1	2.877	1.45325
16	75/4	76/2	2.877	1.49507
17	76/1	76/3	2.325	1.53809
18	76/2	76/4	2.325	1.57305
19	76/3	76/5	2.325	1.61044
20	76/4	77/1	2.325	1.64780
21	77/1	77/2	2.400	1.68619
22	77/2	77/3	2.400	1.72665
23	77/3	77/4	2.400	1.76810
24	77/4	78/1	2.400	1.81054
25	78/1	78/2	1.750	1.85399
26	78/2	78/3	1.750	1.88644
27	78/3	78/4	1.750	1.91945
28	78/4	79/1	1.750	1.95304
29	79/1	79/2	1.750	1.98722
30	79/2	79/3	1.750	2.02199
31	79/3	79/4	1.750	2.05738
32	79/4	80/1	1.750	2.09338
33	80/1	80/2	1.750	2.13002
34	80/2	80/3	1.750	2.16729
35	80/3	80/4	1.750	2.20522
36	80/4	81/1	1.750	2.24381
37	81/1	81/2	1.750	2.28308
38	81/2	81/3	1.750	2.32303
39	81/3	81/4	1.750	2.36368
40	81/4	82/1	1.750	2.40505
41	82/1	82/2	1.750	2.44714
42	82/2	82/3	1.750	2.48996
43	82/3	82/4	1.750	2.53354
44	82/4	83/1	1.750	2.57787
45	83/1	83/2	1.750	2.62298
46	83/2	83/3	1.750	2.66889
47	83/3	83/4	1.750	2.71559
48	83/4	84/1	1.750	2.76312
49	84/1	84/2	1.750	2.81147
50	84/2	84/3	1.750	2.86067
51	84/3	84/4	1.750	2.91073
52	84/4	85/1	1.750	2.96167

TABLE 22. (Concluded)

QTR	CALENDER YR/QTR	FISCAL YR/QTR	INFLATION RATE	CUMULATIVE INFLATION
53	85/1	85/2	1.750	3.01350
54	85/2	85/3	1.750	3.06624
55	85/3	85/4	1.750	3.11989
56	85/4	86/1	1.750	3.17449
57	86/1	86/2	1.750	3.23005
58	86/2	86/3	1.750	3.28657
59	86/3	86/4	1.750	3.34409
60	86/4	87/1	1.750	3.40261
61	87/1	87/2	1.750	3.46215
62	87/2	87/3	1.750	3.52274
63	87/3	87/4	1.750	3.58439
64	87/4	88/1	1.750	3.64712
65	88/1	88/2	1.750	3.71094
66	88/2	88/3	1.750	3.77588
67	88/3	88/4	1.750	3.84196
68	88/4	89/1	1.750	3.90920
69	89/1	89/2	1.750	3.97761
70	89/2	89/3	1.750	4.04721
71	89/3	89/4	1.750	4.11804
72	89/4	90/1	1.750	4.19011
73	90/1	90/2	1.750	4.26343
74	90/2	90/3	1.750	4.33804
75	90/3	90/4	1.750	4.41396
76	90/4	91/1	1.750	4.49120
77	91/1	91/2	1.750	4.56980
78	91/2	91/3	1.750	4.64977
79	91/3	91/4	1.750	4.73114
80	91/4	92/1	1.750	4.81394
81	92/1	92/2	1.750	4.89818
82	92/2	92/3	1.750	4.98390
83	92/3	92/4	1.750	5.07112

SUBSYSTEM HARDWARE QUANTITIES

SUBSYSTEM	SHIP SET UNITS	DDT+E FLIGHT UNITS NEW	DDT+E FLIGHT UNITS SPARE	DDT+E FLIGHT UNITS REFURB	OPERATIONAL FLIGHT UNITS NEW	OPERATIONAL FLIGHT UNITS SPARE	OPERATIONAL FLIGHT UNITS REFURB	TOTAL NEW HARDWARE
TM1								
MANAGEMENT	1	0	0	0	974	0	0	974
TM2								
PRJCT ENG+INTGR	1	0	0	0	974	0	0	974
TM3								
SPRT EQPT+TOOL	1	0	0	0	974	0	0	974
TM4								
PLAN+DIR,TECH SPT	1	0	0	0	974	0	0	974
LABOR, CASE	1	1	0	0	974	0	0	975
AFT CYL, CASE	2	2	0	0	159	0	0	161
FWD CYL, CASE	2	2	0	0	187	0	0	189
AFT STIF TEE,CASE	2	2	0	0	91	0	0	93
CYL, OTH SEG,CASE	4	3	0	0	292	0	0	295
FWD,OTH SEG,CASE	1	1	0	0	73	0	0	74
ATCH,OTH SEG,CASE	1	1	0	0	73	0	0	74
AFT,OTH SEG,CASE	1	1	0	0	73	0	0	74
JT HRD,SEG,CASE	1	1	0	0	73	0	0	74
REFURB, CASE	1	0	0	0	902	0	0	902
LABOR, NOZ	1	2	0	0	974	0	0	976
ELASTOMER,NOZ	1	2	0	0	392	0	0	394
BEARING SHIMS,NOZ	1	2	0	0	75	0	0	77
AFT END RING,NOZ	1	2	0	0	88	0	0	93
FWD END RING,NOZ	1	2	0	0	82	0	0	84
COMP RING, NOZ	1	1	0	0	143	0	0	144
OTH PRTS, NOZ	1	1	0	0	74	0	0	75
REFURB, NOZZLE	1	0	0	0	901	0	0	901
LABOR, IGNITER	1	2	0	0	974	0	0	976
MET PRTS,IGNITER	1	1	0	0	73	0	0	74
REFURB, IGNITER	1	0	0	0	902	0	0	902
LAB&MAT,PROPELNT	1	2	0	0	974	0	0	976
LAB&MAT,INS&LINER	1	2	0	0	974	0	0	976
LABOR,ELECTRICAL	1	2	0	0	974	0	0	976
LAB&MAT,MTR FIN	1	2	0	0	974	0	0	976
MISC MATERIALS	1	2	0	0	974	0	0	976
TM5								
MULTI ELEM SUPORT	1	0	0	0	974	0	0	974

Figure 35. Hardware quantities of each element.

SUBSYSTEM HARDWARE TOTAL COST - FY1976/1 K$

SUBSYSTEM	DEVELOPMENT FLIGHTS NEW	DEVELOPMENT FLIGHTS SPARE	DEVELOPMENT FLIGHTS REFURB	OPERATIONAL FLIGHTS NEW	OPERATIONAL FLIGHTS SPARES	OPERATIONAL FLIGHTS REFURBS	TOTAL OP. FLIGHTS
1.1							
MANAGEMENT	0.	0.	0.	17751.	0.	0.	17751.
1.2							
[illegible] ENG+INTGR	0.	0.	0.	18568.	0.	0.	18568.
1.3							
SPRT EQPT+TOOL	0.	0.	0.	12070.	0.	0.	12070.
1.4							
PLAN+CIR,TECH SPT	0.	0.	0.	53596.	0.	0.	53596.
LABOR, CASE	17.	0.	0.	4841.	0.	0.	4841.
AFT CYL, CASE	365.	0.	0.	23221.	0.	0.	23221.
FWD CYL, CASE	265.	0.	0.	19686.	0.	0.	19686.
AFT STIF RE,CASE	26.	0.	0.	734.	0.	0.	734.
CYL, OTH SEG,CASE	366.	0.	0.	28382.	0.	0.	28382.
FWD,OTH SEG,CASE	226.	0.	0.	13174.	0.	0.	13174.
ATCH,OTH SEG,CASE	166.	0.	0.	11148.	0.	0.	11148.
AFT,OTH SEG,CASE	263.	0.	0.	12161.	0.	0.	12161.
JT HDG,SEG,CASE	20.	0.	0.	1483.	0.	0.	1483.
REFURB, CASE	0.	0.	0.	29786.	0.	0.	29786.
LABOR, NOZ	668.	0.	0.	368119.	0.	0.	368119.
ELASTOMER, NOZ	93.	0.	0.	13637.	0.	0.	13637.
BEARING SHIMS, NOZ	229.	0.	0.	6821.	0.	0.	6821.
AFT END RING,NOZ	119.	0.	0.	3771.	0.	0.	3771.
FWD END RING, NOZ	129.	0.	0.	3531.	0.	0.	3531.
COMP RING, NOZ	45.	0.	0.	3519.	0.	0.	3519.
OTH PRTS, NOZ	191.	0.	0.	11920.	0.	0.	11023.
REFURB, NOZZLE	0.	0.	0.	6281.	0.	0.	6281.
LABOR, IGNITER	25.	0.	0.	8752.	0.	0.	8752.
MET PRTS,IGNITER	15.	0.	0.	948.	0.	0.	948.
REFURB, IGNITER	1.	0.	0.	1599.	0.	0.	1598.
LAB&MAT,PROPELNT	1579.	0.	0.	709334.	0.	0.	709330.
LAB&MAT,INS&LINER	250.	0.	0.	74284.	0.	0.	74284.
LABOR,ELECTRICAL	33.	0.	0.	8939.	0.	0.	8939.
LAB&MAT,MTR FIN	249.	0.	0.	87524.	0.	0.	87524.
MISC MATERIALS	8.	0.	0.	3682.	0.	0.	3680.
1.5							
MULTI ELEM SUPORT	0.	0.	0.	67102.	0.	0.	67132.
TOTALS	5494.	0.	0.	1625113.	0.	0.	1625118.

Figure 36. Total hardware cost for DDT&E and operational flights.

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SUBSYSTEM HARDWARE AVERAGE UNIT COST - FY1976/1 K$

SUBSYSTEM	DEVELOPMENT FLIGHTS		OPERATIONAL FLIGHTS	
	NEW	REFURB	NEW	REFURB
TM1				
MANAGEMENT	0.0	0.0	18.2	0.0
TM2				
PRJCT ENG+INTGR	0.0	0.0	19.1	0.0
TM3				
SPRT EQPT+TOOL	0.0	0.0	12.4	0.0
TM4				
PLAN+DIR,TECH SPT	0.0	0.0	55.0	0.0
LABOR, CASE	19.2	0.0	5.0	0.0
AFT CYL, CASE	182.5	0.0	146.0	0.0
FWD CYL, CASE	132.7	0.0	105.3	0.0
AFT STIF TEE,CASE	9.8	0.0	8.1	0.0
CYL, OTH SEG,CASE	122.6	0.0	96.2	0.0
FWD,OTH SEG,CASE	220.1	0.0	180.5	0.0
ATCH,OTH SEG,CASE	186.2	0.0	152.7	0.0
AFT,OTH SEG,CASE	203.2	0.0	166.6	0.0
JT HRD,SEG,CASE	20.3	0.0	20.3	0.0
REFURB, CASE	0.0	0.0	33.0	0.0
LABOR, NOZ	444.2	0.0	377.9	0.0
ELASTOMER,NOZ	49.0	0.0	34.8	0.0
BEARING SHIMS,NOZ	114.4	0.0	90.9	0.0
AFT END RING,NOZ	[illegible]4.5	0.0	42.9	0.0
FWD END RING,NOZ	54.5	0.0	43.1	0.0
COMP RING, NOZ	44.9	0.0	34.2	0.0
OTH PRTS, NOZ	191.2	0.0	148.9	0.0
REFURB, NOZZLE	0.0	0.0	7.0	0.0
LABOR, IGNITER	12.4	0.0	9.0	0.0
MET PRTS,IGNITER	15.2	0.0	12.4	0.0
REFURB, IGNITER	0.0	0.0	1.8	0.0
LAB&MAT,PROPELNT	789.3	0.0	728.3	0.0
LAB&MAT,INS&LINER	124.8	0.0	76.3	0.0
LABOR,ELECTRICAL	16.3	0.0	9.2	0.0
LAB&MAT,MTR FIN	124.4	0.0	89.9	0.0
MISC MATERIALS	3.8	0.0	3.8	0.0
TM5				
MULTI ELEM SUPORT	0.0	0.0	68.9	0.0

Figure 37. Subsystem hardware on unit cost basis.

SUBSYSTEM HARDWARE COST PER FLIGHT - FY1976/1

SUBSYSTEM	DDT+E FLIGHTS	OPERATIONAL FLIGHTS NEW	SPARES	REFURB	OP. FLIGHTS
TM1					
MANAGEMENT	0.0	36.4	0.0	0.0	36.4
TM2					
PRJCT ENG+INTGR	0.0	38.1	0.0	0.0	38.1
TM3					
SPRT EQPT+TOOL	0.0	24.8	0.0	0.0	24.8
TM4					
PLAN+DIR,TECH SPT	0.0	110.1	0.0	0.0	110.1
LABOR, CASE	3.2	9.9	0.0	0.0	9.9
AFT CYL, CASE	60.8	47.7	0.0	0.0	47.7
FWD CYL, CASE	44.2	40.4	0.0	0.0	40.4
AFT STIF TEE,CASE	3.3	1.5	0.0	0.0	1.5
CYL, OTH SEG,CASE	61.3	57.7	0.0	0.0	57.7
FWD,OTH SEG,CASE	36.7	27.1	0.0	0.0	27.1
ATCH,OTH SEG,CASE	31.0	22.9	0.0	0.0	22.9
AFT,OTH SEG,CASE	33.9	25.0	0.0	0.0	25.0
JT HRD,SEG,CASE	3.4	3.0	0.0	0.0	3.0
REFURB, CASE	0.0	61.2	0.0	0.0	61.2
LABOR, NOZ	148.1	755.9	0.0	0.0	755.9
ELASTOMER,NOZ	16.3	28.0	0.0	0.0	28.0
BEARING SHIMS,NOZ	38.1	14.0	0.0	0.0	14.0
AFT END RING,NOZ	18.2	7.7	0.0	0.0	7.7
FWD END RING,NOZ	18.2	7.2	0.0	0.0	7.2
COMP RING, NOZ	7.5	7.2	0.0	0.0	7.2
OTH PRTS, NOZ	31.9	22.6	0.0	0.0	22.6
REFURB, NOZZLE	0.0	12.9	0.0	0.0	12.9
LABOR, IGNITER	4.1	18.0	0.0	0.0	18.0
MET PRTS,IGNITER	2.5	1.9	0.0	0.0	1.9
REFURB, IGNITER	0.0	3.3	0.0	0.0	3.3
LAB&MAT,PROPELNT	263.1	1456.5	0.0	0.0	1456.5
LAB&MAT,INS&LINER	41.6	152.5	0.0	0.0	152.5
LABOR,ELECTRICAL	5.4	18.4	0.0	0.0	18.4
LAB&MAT,MTR FIN	41.5	179.7	0.0	0.0	179.7
MISC MATERIALS	1.3	7.6	0.0	0.0	7.6
TM5					
MULTI ELEM SUPORT	0.0	137.8	0.0	0.0	137.8
TOTALS	916.	3337.	0.	0.	3337.

Figure 38. CPF per subsystem component.

TOTAL COST PER FLIGHT - FY1976/1

CPF ELEMENT	OPERATIONAL FLIGHTS TOTAL PROGRAM COST	COST PER FLIGHT
HARDWARE		
TM1	17750.8	36.4
TM2	18567.7	38.1
TM3	12070.4	24.8
TM4	1509626.6	3099.9
TM5	67102.3	137.8
TOTALS	1625117.9	3337.0

Figure 39. CFP for SRM.

S U B S Y S T E M	SHIP SET UNITS	DDT&E FLIGHT UNITS NEW	DDT&E FLIGHT UNITS SPARE	DDT&E FLIGHT UNITS REFURB	OPERATIONAL FLIGHT UNITS NEW	OPERATIONAL FLIGHT UNITS SPARE	OPERATIONAL FLIGHT UNITS REFURB	TOTAL NEW HARDWARE
SAC TVC								
TVC NEW	1	0	0	0	1	0	0	1
SUB RECOVERY								
PILOT CHUTE	1	2	0	0	974	0	0	976
DROGUE CHUTE	1	2	0	0	131	0	0	133
MAIN CHUTE	3	4	0	0	388	0	0	392
PARA LOC AID	3	4	0	0	346	0	1289	350
MCHT SUPT STRUC	1	2	0	0	58	0	0	60
SUB TVC								
ACTUATOR	2	3	0	0	259	0	434	262
POWER SUPPLY	2	3	0	0	178	0	807	181
SUB STRUCTURES								
NOSE CAP	1	1	0	0	974	0	0	975
NOSE FRUSTUM	1	1	0	0	58	0	461	59
SEPARATION RING	1	1	0	0	974	0	0	975
FWD SKIRT	1	1	0	0	36	0	472	37
FWD TUNNEL	1	1	0	0	37	0	472	38
AFT TUNNEL	1	1	0	0	39	0	469	40
REUSABLE STRUTS	1	1	0	0	36	0	477	37
EXPNDBL STRUTS	1	0	0	0	974	0	0	974
ET ATTACH RING	1	1	0	0	36	0	471	37
AFT SKIRT	1	1	0	0	121	0	427	122
THERMAL SHIELD	1	1	0	0	974	0	0	975
SUB E+I								
INTEGR ELEC ASMBL	2	3	0	0	117	0	916	120
ALTITUDE SWITH	1	2	0	0	59	0	462	61
FRUSTUM LOCAT AID	1	2	0	0	58	0	457	60
RF BEACON	1	2	0	0	57	0	462	59
RF BEACON ANTENNA	1	2	0	0	54	0	465	56
FLASHING LIGHT	1	2	0	0	143	0	415	145
RATE GYRO	3	3	0	0	177	0	1383	180
CABLE-REUSABLE	1	2	0	0	57	0	463	59
SENSORS	2	4	0	0	143	0	986	147
RECOVERY BATTERY	1	1	0	0	974	0	0	975
FRUSTUM BATTERY	1	1	0	0	974	0	0	975
CABLE-THROWAY	1	1	0	0	974	0	0	975
SUB SEP MOTORS								
SEPARATION MOTORS	8	7	0	0	7788	0	0	7795
SUB PYROTECHNICS								
PYROTECHNICS	1	2	0	0	974	0	0	976

Figure 40. Subsystem hardware quantities.

SUBSYSTEM	DEVELOPMENT FLIGHTS NEW	DEVELOPMENT FLIGHTS SPARE	DEVELOPMENT FLIGHTS REFURB	OPERATIONAL FLIGHTS NEW	OPERATIONAL FLIGHTS SPARES	OPERATIONAL FLIGHTS REFURBS	TOTAL OP. FLIGHTS
GAC TVC							
TVC NEW	0.	0.	0.	7535.	0.	0.	7535.
SUB RECOVERY							
PILOT CHUTE	2.	0.	0.	555.	0.	0.	555.
DROGUE CHUTE	86.	0.	0.	3648.	0.	0.	3648.
MAIN CHUTE	375.	0.	0.	17829.	0.	0.	17829.
PARA LOC AID	61.	0.	0.	3221.	0.	550.	3771.
MCNT SUPT STRUC	148.	0.	0.	3724.	0.	0.	3724.
SUB TVC							
ACTUATOR	490.	0.	0.	23276.	0.	2264.	25540.
POWER SUPPLY	1198.	0.	0.	40861.	0.	5933.	46795.
SUB STRUCTURES							
NOSE CAP	31.	0.	0.	13312.	0.	0.	13312.
NOSE FRUSTUM	349.	0.	0.	8139.	0.	6381.	14520.
SEPARATION RING	37.	0.	0.	7929.	0.	0.	7929.
FWD SKIRT	439.	0.	0.	6910.	0.	10277.	17187.
FWD TUNNEL	29.	0.	0.	513.	0.	219.	732.
AFT TUNNEL	16.	0.	0.	354.	0.	121.	475.
REUSABLE STRUTS	67.	0.	0.	1438.	0.	809.	2247.
EXPNDBL STRUTS	0.	0.	0.	39381.	0.	0.	39381.
FT ATTACH RING	144.	0.	0.	3114.	0.	434.	3548.
AFT SKIRT	1042.	0.	0.	47388.	0.	13965.	61353.
THERMAL SHIELD	27.	0.	0.	6973.	0.	0.	6973.
SUB E+I							
INTEGR ELEC ASSML	1345.	0.	0.	35375.	0.	19645.	55020.
ALTITUDE SWITCH	12.	0.	0.	237.	0.	155.	392.
FRUSTUM LOCAT AID	35.	0.	0.	656.	0.	242.	898.
RF BEACON	16.	0.	0.	185.	0.	93.	278.
RF BEACON ANTENNA	1.	0.	0.	9.	0.	6.	15.
FLASHING LIGHT	4.	0.	0.	153.	0.	29.	182.
RATE GYRO	126.	0.	0.	4267.	0.	1342.	5609.
CABLE-REUSABLE	144.	0.	0.	1845.	0.	1314.	3158.
SENSORS	18.	0.	0.	222.	0.	62.	284.
RECOVERY BATTERY	4.	0.	0.	1128.	0.	0.	1128.
FRUSTUM BATTERY	1.	0.	0.	376.	0.	0.	376.
CABLE-THRUWAY	12.	0.	0.	3305.	0.	0.	3305.
SUB SEP MOTORS							
SEPARATION MOTORS	34.	0.	0.	23160.	0.	0.	23160.
SUB PYROTECHNICS							
PYROTECHNICS	93.	0.	0.	45292.	0.	0.	45292.
TOTALS	6219.	0.	0.	352393.	0.	56419.	408812.

Figure 41. Subsystem hardware total cost - FY1976/1 K$.

SUBSYSTEM	DEVELOPMENT FLIGHTS NEW	DEVELOPMENT FLIGHTS REFURB	OPERATIONAL FLIGHTS NEW	OPERATIONAL FLIGHTS REFURB
BAC TVC				
TVC NEW	[illegible]	[illegible]	7534.6	0.0
SUB RECOVERY				
PILOT CHUTE	1.1	[illegible]	0.6	0.0
DROGOGUE CHUTE	42.8	[illegible]	27.6	0.0
MAIN CHUTE	76.1	[illegible]	36.6	0.0
PARA LOC AID	15.2	[illegible]	9.3	0.4
MCHT SUPT STRUC	69.0	[illegible]	54.2	0.0
SUB TVC				
ACTUATOR	164.7	[illegible]	83.9	2.7
POWER SUPPLY	399.3	[illegible]	229.6	6.7
SUB STRUCTURES				
NOSE CAP	31.5	[illegible]	15.7	0.3
NOSE FRUSTUM	339.4	[illegible]	140.3	13.8
SEPARATION RING	36.5	[illegible]	9.1	0.0
FWD SKIRT	498.6	[illegible]	191.9	21.8
FWD TUNNEL	27.9	[illegible]	13.9	3.4
AFT TUNNEL	13.4	[illegible]	9.1	0.3
REUSABLE STRUTS	67.3	[illegible]	51.1	9.9
EXPNDBL STRUTS	[illegible]	[illegible]	40.4	0.0
ET ATTACH RING	133.9	[illegible]	36.5	0.9
AFT SKIRT	1482.1	[illegible]	391.6	32.7
THERMAL SHIELD	20.4	[illegible]	7.2	0.0
SUB E+I				
INTEGR ELEC ASMBL	446.3	[illegible]	502.4	16.0
ALTITUDE SWITH	6.2	[illegible]	4.4	0.3
FRUSTUM LOCAT AID	17.5	[illegible]	11.3	0.5
RF BEACON	5.0	[illegible]	3.2	0.2
RF BEACON ANTENNA	[illegible]	[illegible]	0.2	0.0
FLASHING LIGHT	1.9	[illegible]	1.1	0.1
RATE GYRO	41.6	[illegible]	24.1	1.0
CABLE-REUSABLE	49.9	[illegible]	32.4	2.9
SENSORS	2.6	[illegible]	1.6	0.1
RECOVERY BATTERY	4.5	[illegible]	1.2	0.0
FRUSTUM BATTERY	1.5	[illegible]	0.4	0.0
CABLE-THROWAY	11.9	[illegible]	3.1	0.0
SUB SEP MOTORS				
SEPARATION MOTORS	4.9	[illegible]	3.0	0.0
SUB PYROTECHNICS				
PYROTECHNICS	46.5	1.1	46.5	0.0

Figure 42. Subsystem hardware average unit cost - FY1976/1 K$.

SUBSYSTEM	DDT&E FLIGHTS	OPERATIONAL FLIGHTS NEW	SPARES	REFURB	OP. FLIGHTS
EAC TVC					
TVC NEW	[illegible]	15.5	[illegible]	[illegible]	15.5
SUB RECOVERY					
PILOT CHUTE	0.4	1.1	[illegible]	[illegible]	1.1
DROGUE CHUTE	14.3	7.5	[illegible]	[illegible]	7.5
MAIN CHUTE	56.8	36.6	[illegible]	0.0	36.6
PARA LOC AID	10.2	6.6	[illegible]	1.1	7.7
VCHT SUPT STRUC	23.3	7.6	[illegible]	[illegible]	7.6
SUB TVC					
ACTUATOR	22.4	47.9	[illegible]	4.6	52.4
POWER SUPPLY	199.7	85.4	[illegible]	12.2	96.1
SUB STRUCTURES					
NOSE CAP	5.2	27.3	[illegible]	0.0	27.3
NOSE FRUSTUM	54.2	16.7	[illegible]	13.1	29.8
SEPARATION RING	6.1	16.3	[illegible]	[illegible]	16.3
FWD SKIRT	66.1	14.2	[illegible]	21.1	35.3
FWD TUNNEL	4.6	1.1	[illegible]	0.4	1.4
AFT TUNNEL	3.1	0.7	[illegible]	0.2	1.2
REUSABLE STRUTS	11.2	3.8	[illegible]	0.8	4.6
EXPENDBL STRUTS	3.6	83.9	[illegible]	[illegible]	83.9
ET ATTACH RING	24.8	6.4	[illegible]	0.9	7.3
AFT SKIRT	173.7	97.5	[illegible]	28.7	126.3
THERMAL SHIELD	5.4	14.3	[illegible]	0.3	14.3
SUB E+I					
INTEGR ELEC ASMBL	224.2	72.6	[illegible]	30.1	102.7
ALTITUDE SWITCH	2.1	2.5	[illegible]	0.3	2.8
FRUSTUM LOCAT AID	5.8	1.3	[illegible]	0.5	1.8
RF BEACON	1.7	[illegible]	[illegible]	0.2	0.6
RF BEACON ANTENNA	0.1	[illegible]	[illegible]	0.0	[illegible]
FLASHING LIGHT	[illegible]	[illegible]	[illegible]	0.1	[illegible]
RATE GYRO	[illegible]	8.7	[illegible]	2.8	11.5
CABLE-REUSABLE	16.6	3.8	[illegible]	2.7	6.5
SENSORS	1.7	[illegible]	[illegible]	0.1	0.6
RECOVERY BATTERY	[illegible]	2.3	[illegible]	0.0	2.3
FRUSTUM BATTERY	[illegible]	[illegible]	[illegible]	[illegible]	0.8
CABLE-THROWAY	2.4	6.2	[illegible]	[illegible]	6.2
SUB SEP MOTORS					
SEPARATION MOTORS	5.7	47.6	[illegible]	[illegible]	47.6
SUB PYROTECHNICS					
PYROTECHNICS	15.5	93.1	[illegible]	[illegible]	93.1
TOTALS	[illegible]	[illegible]	[illegible]	124.	844.

Figure 43. Subsystem hardware cost per flight - FY1976/1 k$.

CPF ELEMENT	OPERATIONAL FLIGHTS TOTAL PROGRAM COST	COST PER FLIGHT
HARDWARE		
BAC TVC	7534.6	15.5
SUB RECOVERY	28969.1	59.5
SUB TVC	64137.6	131.7
SUB STRUCTURES	135848.8	279.0
SUB E+I	47450.5	97.4
SUB SEP MOTORS	23160.4	47.[illegible]
SUB PYROTECHNICS	45292.4	93.0
SPARE		
REFURBISHMENT		
BAC RECOVERY	550.2	1.1
SUB TVC	8196.8	16.8
SUB STRUCTURES	31777.3	65.3
SUB E+I	17894.0	36.7
PROJ MGMT-INC2	1776.2	3.6
FAC OPS+MT-REF-INC2	373.2	0.8
PROJ ENG+INTG-INC2	1519.4	3.1
SAFE+QUAL ASSU-INC2	549.7	1.1
LOGSTCS SPRT-INC2	883.6	1.8
ASSY+CHKOUT-INC2+3	32248.4	66.2
REFURBISH-INC2+3	15344.3	31.5
PROJ MGMT-INC3	14530.4	29.8
FAC OPS+MT-REF-INC3	5843.2	12.0
PROJ ENG+INTG-INC3	13555.9	27.8
SAFE+QUAL ASSU-INC3	12295.8	25.2
LOGSTCS SPRT-INC3	8268.8	17.0
SRB TRANSPORT ETR	16601.0	34.1
SRB TRANSPORT WTR	5981.9	12.3
T O T A L S	54[illegible]5[illegible]3.5	111[illegible].0

Figure 44. Total cost per flight - FY1976/1 K$.

The Solid Rocket Motor (SRM) part of the SRB is illustrated in Figures 35 through 39. The hardware quantities of each element of the SRM are shown in Figure 35. The designations TM1 - TM5 in Figure 35 reflect the work breakdown structure (WBS) used by the prime SRM contractor, Thiokol Corporation, for contract administration. The 974 units of project management reflect the use of a cost/SRB methodology for 487 operational flights of management support. The units under "DDT&E Flight Units New" represent the learning curve start unit which implements a 50 percent production gap penalty. A shipset is defined as the number of units of a subsystem needed to make one SRB.

The total hardware cost for DDT&E and operational flights is shown in Figure 36. The designation "FY1976/1K$" means first quarter of fiscal year 1976 dollars and is equivalent to the terminology "1975$." Thus, in terms of run-out cost, the SRM portion of the SRB is expected to cost $1.63 billion in 1975$. On a unit cost basis, the results are as shown in Figure 37. Figure 38 shows the cost-per-flight per subsystem component. The total cost-per-flight for SRM is $3.34 million as shown in Figure 39.

CPF program data and results for the remaining hardware and services for the SRB are presented in Figures 40 through 44. The hardware is expected to be procured through a booster assembly contractor (BAC). The BAC will either manufacture the hardware or subcontract it out. The indication "BAC" means it is anticipated the BAC will manufacture this hardware, and "SUB" means it is anticipated he will subcontract those components out. The BOSIM analysis of new hardware quantity requirements appears in the column "Operational Flight Units - New" in Figure 40. The format for data on total program cost, average unit cost and subsystem CPF in Figures 41, 42, and 43 is the same as previously discussed for the SRM.

The total CPF data in Figure 44 includes cost for the BAC itself. The designation "INC 2" means the first 21 operational flights, and "INC 3" means the balance of the traffic model. The four line items of "Refurbishment" could be regarded as depot level maintenance costs.

V. REAL YEAR COST

Budget estimates generally require cost estimates in real year dollars. Schedules for hardware deliveries and the performance of service operations do not affect a constant dollar cost calculation. However, due to inflation, schedules are crucial to real year dollar cost estimates. A WBS containing 140 elements has been constructed for the operational flight phase of the SRB project. Each element is costed over the traffic model. The Annual Cost Program (ACP) computer model performs the calculation. Long lead hardware funding requirements are an important part of a real year cost estimate.

A. Work Breakdown Structure

The WBS is organized consistent with how the SRB project is expected to be managed during operational flights. A prime SRM contractor delivers loaded motors to the launch site and returns recovered empty motor cases to his facility for refurbishment and reloading. The launch site Booster Assembly Contractor (BAC) has a large subcontract effort to procure the remaining hardware (E&I, recovery, separation, TVC, structures, pyrotechnics). The BAC also performs assembly and checkout of the complete SRB as well as refurbishment of recovered SRB's, except for the SRM as previously mentioned. From a budgeting standpoint three line items make up the total SRB project cost: SRM, SRB and LOGISTICS. LOGISTICS is small compared to SRM and SRB and contains essentially transportation costs. The SRB line item is understood to contain new hardware procurement as well as launch site assembly, checkout and refurbishment operations of the BAC. Figure 45 presents the WBS. The designations NASA 1 and THIOK 1 indicate the applicable inflation table.

B. Long-Lead Funding

Payments in advance of hardware delivery, whether they are called progress payments or long lead funding, are occasionally required. The technique for handling this from a budget standpoint is first to estimate the cost as if it were paid C.O.D.; i.e., when the hardware is actually delivered on dock at the launch site. Then, if partial payments are required prior to delivery, the percentage of the total required is spread out over as many quarters prior to delivery as necessary. Table 23 shows typical spread functions. The "0" quarter is the quarter of delivery. The numbers are percentages and total 100 for each subsystem.

C. Total Resource Schedules

Cost/flight and level of effort type functions can be considered to have a "delivery schedule" in the sense that they are performed or "delivered" at a certain time. Functions such as management and project engineering and integration fall in this category. Figure 46 shows delivery schedules for these non-hardware items from 1977-1992. Actual hardware delivery schedules are shown in terms of the number of units per quarter from 1977-1992 in Figure 47. Refurbishment schedules are illustrated in Figure 48.

1.0	1	SOLID ROCKET BOOSTER	
1.1.0	2	SOLID ROCKET MOTOR	
1.1.1	3	SRM MANAGEMENT	THIOK1
1.1.2	4	SRM PROJECT ENG. + INTEGRATION	THIOK1
1.1.3	5	SRM SUPPORT EQPT + TOOLING MAINT.	THIOK1
1.1.4.0	6	SRM DELIVERABLE HARDWARE	
1.1.4.1	7	SRM PLANNING + DIRECT TECH SUPPORT	THIOK1
1.1.4.2.0	8	S R M CASE	
1.1.4.2.1	9	SRM CASE LABOR	THIOK1
1.1.4.2.2	10	SRM CASE AFT CYLINDER	THIOK1
1.1.4.2.3	11	SRM CASE FWD CYLINDER	THIOK1
1.1.4.2.4	12	SRM CASE AFT STIFFNESS TEES	THIOK1
1.1.4.2.5	13	SRM CASE CYLINDER OTHER SEGMENTS	THIOK1
1.1.4.2.6	14	SRM CASE CYLINDER OTH SEG FWD	THIOK1
1.1.4.2.7	15	SRM CASE CYLINDER OTH SEG ATT	THIOK1
1.1.4.2.8	16	SRM CASE CYLINDER OTH SEG AFT	THIOK1
1.1.4.2.9	17	SRM CASE CYLINDER OTH SEG JT HDWR	THIOK1
1.1.4.2.10	18	SRM CASE REFURB	THIOK1
1.1.4.3.0	19	SRM NOZZLE	
1.1.4.3.1	20	SRM NOZZLE LABOR	THIOK1
1.1.4.3.2	21	SRM NOZZLE COMPLIANCE RING	THIOK1
1.1.4.3.3	22	SRM NOZZLE OTHER PARTS	THIOK1
1.1.4.3.4	23	SRM NOZZLE ELASTOMER	THIOK1
1.1.4.3.5	24	SRM NOZZLE BEARING SHIMS	THIOK1
1.1.4.3.6	25	SRM NOZZLE AFT END RING	THIOK1
1.1.4.3.7	26	SRM NOZZLE FWD END RING	THIOK1
1.1.4.3.8	27	SRM NOZZLE REFURB	THIOK1
1.1.4.4.0	28	SRM IGNITER	
1.1.4.4.1	29	SRM IGNITER LABOR	THIOK1
1.1.4.4.2	30	SRM IGNITER METAL PARTS	THIOK1
1.1.4.4.3	31	SRM IGNITER REFURB	THIOK1
1.1.4.5	32	SRM PROPELLANT	THIOK1
1.1.4.6	33	SRM INSULATION AND LINER	THIOK1
1.1.4.7	34	SRM ELECTRICAL	THIOK1
1.1.4.8	35	SRM MATERIAL FINISHING + INSPECTION	THIOK1
1.1.4.9	36	SRM MISCELLANEOUS MATERIALS	THIOK1
1.1.5	37	SRM MULTI ELEMENT SUPPORT	THIOK1
1.2.0	38	SOLID ROCKET BOOSTER SUBSYSTEMS	
1.2.1.0	39	SRB FLIGHT HARDWARE	
1.2.1.1.0	40	BAC TVC NEW	NASA1
1.2.1.1.2.0	48	THRUST VECTOR CONTROL	NASA1
1.2.1.1.2.1	49	BAC TVC NEW HARDWARE	NASA1
1.2.1.2.0	70	NEW HARDWARE SUB	
1.2.1.2.1.0	71	SUB E+I NEW	
1.2.1.2.1.1	72	INTGRTD ELCTRNC ASSMBLY NEW	NASA1
1.2.1.2.1.6	77	ALTITUDE SWITCH NEW	NASA1
1.2.1.2.1.7	78	FRUSTUM LOCATION AID	NASA1
1.2.1.2.1.8	79	RF BEACON NEW	NASA1
1.2.1.2.1.9	80	RF BEACON ANTENNA NEW	NASA1
1.2.1.2.1.10	81	FLASHING LIGHT NEW	NASA1
1.2.1.2.1.11	82	RATE GYRO NEW	NASA1
1.2.1.2.1.12	83	CABLE REUSABLE NEW	NASA1
1.2.1.2.1.13	84	SENSORS NEW	NASA1
1.2.1.2.1.14	85	RECOVERY BATTERY NEW	NASA1
1.2.1.2.1.15	86	FRUSTUM BATTERY NEW	NASA1
1.2.1.2.1.16	87	CABLE THROUGHWAY NEW	NASA1
1.2.1.2.2.0	88	SUB THRUST VECTOR CONTROL NEW	
1.2.1.2.2.1	89	TVC ACTUATOR NEW	NASA1
1.2.1.2.2.2	90	TVC POWER SUPPLY NEW	NASA1
1.2.1.2.3.0	91	SUB STRUCTURES NEW	
1.2.1.2.3.1	92	NOSE CAP NEW	NASA1
1.2.1.2.3.2	93	NOSE FRUSTUM NEW	NASA1
1.2.1.2.3.3	94	SEPARATION RING NEW	NASA1
1.2.1.2.3.4	95	FWD SKIRT NEW	NASA1
1.2.1.2.3.5	96	FWD TUNNEL NEW	NASA1
1.2.1.2.3.6	97	AFT TUNNEL NEW	NASA1
1.2.1.2.3.7	98	REUSABLE STRUTS NEW	NASA1
1.2.1.2.3.8	99	EXPENDABLE STRUTS NEW	NASA1
1.2.1.2.3.9	100	ET ATTACH RING NEW	NASA1
1.2.1.2.3.10	101	AFT SKIRT NEW	NASA1
1.2.1.2.3.11	102	THERMAL SHIELD NEW	NASA1
1.2.1.2.4.0	103	SUB RECOVERY NEW	NASA1

Figure 45. WBS Directory.

1.2.1.2.4.1	104 PILOT CHUTE	NASA1
1.2.1.2.4.2	105 DROGUE CHUTE	NASA1
1.2.1.2.4.3	106 MAIN CHUTE	NASA1
1.2.1.2.4.4	107 PLA PARACHUTE LOCATION AID	NASA1
1.2.1.2.4.5	108 MAIN PARACHUTE SUPPORT STRUCTURE	NASA1
1.2.1.2.5	109 SUB SEPARATION MOTORS	NASA1
1.2.1.2.6	110 SUB PYROTECHNICS	NASA1
1.2.2.0	111 USBI REFURB	
1.2.2.1	112 USBI REFURB	NASA1
1.2.2.4.0	114 DEPOT LEVEL MAINTENANCE	
1.2.2.4.1.0	115 BAC E+I REFURBISHMENT	
1.2.2.4.1.1	116 INTEGRATED ELECTRONIC ASSEMBLY DLM	NASA1
1.2.2.4.1.6	121 ALTITUDE SWITCH DLM	NASA1
1.2.2.4.1.7	122 FRUSTRUM LOCATION AID DLM	NASA1
1.2.2.4.1.8	123 RF BEACON DLM	NASA1
1.2.2.4.1.9	124 RF BEACON ANTENNA DLM	NASA1
1.2.2.4.1.10	125 FLASHING LIGHT DLM	NASA1
1.2.2.4.1.11	126 RATE GYRO DLM	NASA1
1.2.2.4.1.12	127 CABLE REUSABLE DLM	NASA1
1.2.2.4.1.13	128 SENSORS DLM	NASA1
1.2.2.4.2.0	129 BAC TVC DLM	
1.2.2.4.2.1	130 ACTUATOR DLM	NASA1
1.2.2.4.2.2	131 POWER SUPPLY DLM	NASA1
1.2.2.4.3.0	132 BAC STRUCTURES DLM	
1.2.2.4.3.1	133 NOSE FRUSTRUM DLM	NASA1
1.2.2.4.3.2	134 FORWARD SKIRT	NASA1
1.2.2.4.3.3	135 FORWARD TUNNEL DLM	NASA1
1.2.2.4.3.4	136 AFT TUNNEL DLM	NASA1
1.2.2.4.3.5	137 REUSABLE STRUTS BAC DLM	NASA1
1.2.2.4.3.6	138 AFT SKIRT BAC REF	NASA1
1.2.2.4.3.7	139 ET ATTACH RING BAC DLM	NASA1
1.2.2.4.4.0	140 BAC RECOVERY DLM	
1.2.2.4.4.1	141 SATELLITE FLOATS BAC DLM	NASA1
1.2.3.0	157 SRB PROJECT MANAGEMENT	
1.2.3.1	158 SRB PROJECT MANAGEMENT	NASA1
1.2.4.0	164 SRB REFURB SUBASSY FAC OPS + MAINT	
1.2.4.1	165 SRB REFURB SUBASSY FAC OPS + MAINT	NASA1
1.2.5	171 SRB PROJECT ENGR + INTEGRATION	NASA1
1.2.6.0	172 SRB SAFETY RELIABILITY + QUALASSUR	
1.2.6.1	173 SRB SAFETY.RELIABILITY + QUALASSUR	NASA1
1.2.7.0	177 SRB LOGISTICS SUPPORT	
1.2.7.1	178 SRB LOGISTICS SUPPORT	NASA1
1.2.8.0	179 SRB ASSEMBLY + CHECKOUT	
1.2.8.1	180 SRB ASSEMBLY + CHECKOUT	NASA1
1.3.0	188 LOGISTICS	
1.3.1.0	189 SRB TRANSPORTATION	
1.3.1.1	190 SRB ETR TRANSPORTATION	A1
1.3.1.2	191 SRB UTR TRANSPORTATION	A1

Figure 45. (Concluded).

TABLE 23. SRB COST SPREAD FUNCTIONS

Subsystem	Quarters prior to delivery 7	6	5	4	3	2	1	0
<u>SOLID ROCKET MOTOR</u>								
Aft Cylinder	0	5	15	20	20	20	15	5
Forward Cylinder	0	5	15	20	20	20	15	5
Other Segments	0	5	15	20	20	20	15	5
Aft Stiffner Tees						30	30	40
Nozzle					10	50	30	10
Compliance Ring						30	30	40
Insulation						70	30	0
Igniter						40	50	10
Propellant							80	20
<u>ELECTRONICS AND INSTRUMENTATION</u>								
E & I Forward Skirt			40	20	20	10	10	0
E & I Aft IEA			40	20	20	10	10	0
E & I DDT & E Unique			40	20	20	10	10	0
<u>THRUST VECTOR CONTROL</u>								
Actuator					20	30	30	20
Power Supply						20	40	40
<u>STRUCTURES</u>								
Nose Cap							60	40
Nose Frustum						40	30	30
Separation Ring						45	45	10
Forward Skirt				15	25	25	25	10
Systems Tunnel						20	40	40
ET Attach Ring						30	30	40
SRB/ET Attach Struts							40	60
Aft Skirt				15	25	25	25	10
Thermal Shield							60	40
<u>RECOVERY</u>								
Pilot Chute							50	50
Drogue Chute							50	50
Main Chute						30	40	30
Recovery Aids						40	30	30
<u>PYROTECHNICS</u>					20	20	30	30
<u>SEPARATION MOTORS</u>							50	50

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SUBSYSTEM	FY1977 QTR1	FY1977 QTR2	FY1977 QTR3	FY1977 QTR4	FY1978 QTR1	FY1978 QTR2	FY1978 QTR3	FY1978 QTR4	FY1979 QTR1	FY1979 QTR2	FY1979 QTR3	FY1979 QTR4	FY1980 QTR1	FY1980 QTR2	FY1980 QTR3	FY1980 QTR4
SSRM MANAGEMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM PROJECT ENG. + INTEG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM SUPPORT EQPT + TOOLI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM PLANNING + DIRECT TE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM CASE LABOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM NOZZLE LABOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM IGNITER LABOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM MATERIAL FINISHING +	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRM MULTI ELEMENT SUPPOR	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUSBI REFURB	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	4
SSRB PROJECT MANAGEMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB REFURB SUBASSY FAC O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB PROJECT ENGR + INTEG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB SAFETY.RELIABILITY +	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB LOGISTICS SUPPORT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB ASSEMBLY + CHECKOUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB ETR TRANSPORTATION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB UTR TRANSPORTATION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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SUBSYSTEM	FY1981 QTR1	FY1981 QTR2	FY1981 QTR3	FY1981 QTR4	FY1982 QTR1	FY1982 QTR2	FY1982 QTR3	FY1982 QTR4	FY1983 QTR1	FY1983 QTR2	FY1983 QTR3	FY1983 QTR4	FY1984 QTR1	FY1984 QTR2	FY1984 QTR3	FY1984 QTR4
SSRM MANAGEMENT	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM PROJECT ENG. + INTEG	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM SUPPORT EQPT + TOOLI	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM PLANNING + DIRECT TE	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM CASE LABOR	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM NOZZLE LABOR	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM IGNITER LABOR	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM MATERIAL FINISHING +	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SSRM MULTI ELEMENT SUPPOR	2	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20
SUSBI REFURB	2	4	6	8	4	8	8	2	0	0	0	0	0	0	0	0
SSRB PROJECT MANAGEMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB REFURB SUBASSY FAC O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB PROJECT ENGR + INTEG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB SAFETY.RELIABILITY +	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB LOGISTICS SUPPORT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SSRB ASSEMBLY + CHECKOUT	2	4	6	8	4	8	8	2	0	0	0	0	0	0	0	0
SSRB ETR TRANSPORTATION	1	2	3	4	2	4	4	5	5	5	5	5	7	8	7	8
SSRB UTR TRANSPORTATION	0	0	0	0	0	0	0	0	0	0	0	2	1	1	2	2

Figure 46. Non-hardware increment 2 delivery schedule.

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SUBSYSTEM	FY1985 QTR1	FY1985 QTR2	FY1985 QTR3	FY1985 QTR4	FY1986 QTR1	FY1986 QTR2	FY1986 QTR3	FY1986 QTR4	FY1987 QTR1	FY1987 QTR2	FY1987 QTR3	FY1987 QTR4	FY1988 QTR1	FY1988 QTR2	FY1988 QTR3	FY1988 QTR4
SRM MANAGEMENT	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM PROJECT ENG. + INTEG	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM SUPPORT EQPT + TOOLI	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM PLANNING + DIRECT TE	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM CASE LABOR	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM NOZZLE LABOR	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM IGNITER LABOR	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM MATERIAL FINISHING +	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
SRM MULTI ELEMENT SUPPOR	22	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28
USBI REFURB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB PROJECT MANAGEMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB REFURB SUBASSY FAC O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB PROJECT ENGR + INTEG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB SAFETY.RELIABILITY +	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB LOGISTICS SUPPORT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB ASSEMBLY + CHECKOUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB ETR TRANSPORTATION	8	8	9	9	9	9	9	9	8	8	9	9	10	10	10	10
SRB WTR TRANSPORTATION	3	3	3	4	3	4	4	4	4	5	5	4	4	5	5	4

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SUBSYSTEM	FY1989 QTR1	FY1989 QTR2	FY1989 QTR3	FY1989 QTR4	FY1990 QTR1	FY1990 QTR2	FY1990 QTR3	FY1990 QTR4	FY1991 QTR1	FY1991 QTR2	FY1991 QTR3	FY1991 QTR4	FY1992 QTR1	FY1992 QTR2	FY1992 QTR3	FY1992 QTR4
SRM MANAGEMENT	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM PROJECT ENG. + INTEG	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM SUPPORT EQPT + TOOLI	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM PLANNING + DIRECT TE	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM CASE LABOR	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM NOZZLE LABOR	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM IGNITER LABOR	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM MATERIAL FINISHING +	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
SRM MULTI ELEMENT SUPPOR	24	26	28	28	28	28	30	28	28	28	28	26	26	26	10	0
USBI REFURB	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB PROJECT MANAGEMENT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB REFURB SUBASSY FAC O	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB PROJECT ENGR + INTEG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB SAFETY.RELIABILITY +	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB LOGISTICS SUPPORT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB ASSEMBLY + CHECKOUT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRB ETR TRANSPORTATION	9	9	10	10	10	10	11	10	10	10	9	9	9	9	4	0
SRB UTR TRANSPORTATION	3	4	4	4	4	4	4	4	4	4	5	4	4	4	1	0

Figure 46. (Concluded).

08/28/78 15:24:15 DPA/EL22

NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE

SUBSYSTEM	FY1977 QTR1	QTR2	QTR3	QTR4	FY1978 QTR1	QTR2	QTR3	QTR4	FY1979 QTR1	QTR2	QTR3	QTR4	FY1980 QTR1	QTR2	QTR3	QTR4
SRM CASE AFT CYLINDER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE FWD CYLINDER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE AFT STIFFNESS T	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTHER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTH SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTH SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTH SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTH SE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE COMPLIANCE RI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE OTHER PARTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE ELASTOMER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1
SRM NOZZLE BEARING SHIMS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE AFT END RING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE FWD END RING	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM IGNITER METAL PARTS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM PROPELLANT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM INSULATION AND LINER	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM ELECTRICAL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM MISCELLANEOUS MATERI	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BAC TVC NEW HARDWARE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INTGRTD ELCTRNC ASSMBLY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALTITUDE SWITCH NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRUSTUM LOCATION AID	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RF BEACON NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RF BEACON ANTENNA NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FLASHING LIGHT NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RATE GYRO NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CABLE REUSABLE NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SENSORS NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RECOVERY BATTERY NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FRUSTUM BATTERY NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6
CABLE THROUGHWAY NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
TVC ACTUATOR NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TVC POWER SUPPLY NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOSE CAP NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6
NOSE FRUSTUM NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPARATION RING NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6
FWD SKIRT NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FWD TUNNEL NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AFT TUNNEL NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REUSABLE STRUTS NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EXPENDABLE STRUTS NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
ET ATTACH RING NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AFT SKIRT NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 47. New hardware increment 2 delivery schedule.

06/26/78 15:25:41 DPA/EL22

NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE CONTD

SUBSYSTEM	FY1977 QTR1	FY1977 QTR2	FY1977 QTR3	FY1977 QTR4	FY1978 QTR1	FY1978 QTR2	FY1978 QTR3	FY1978 QTR4	FY1979 QTR1	FY1979 QTR2	FY1979 QTR3	FY1979 QTR4	FY1980 QTR1	FY1980 QTR2	FY1980 QTR3	FY1980 QTR4
THERMAL SHIELD NEW	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PILOT CHUTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
DROGUE CHUTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	[illegible]
MAIN CHUTE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
PLA PARACHUTE LOCATION A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MAIN PARACHUTE SUPPORT S	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUB SEPARATION MOTORS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	32	48
SUB PYROTECHNICS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	6

Figure 47. (Continued).

03/23/73 13:27:03 DPA/ZL02

NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE

SUBSYSTEM	FY1981 QTR1	FY1981 QTR2	FY1981 QTR3	FY1981 QTR4	FY1982 QTR1	FY1982 QTR2	FY1982 QTR3	FY1982 QTR4	FY1983 QTR1	FY1983 QTR2	FY1983 QTR3	FY1983 QTR4	FY1984 QTR1	FY1984 QTR2	FY1984 QTR3	FY1984 QTR4
SRM CASE AFT CYLINDER	0	0	1	1	1	5	6	6	6	6	6	6	6	6	6	6
SRM CASE FWD CYLINDER	0	0	3	3	3	6	6	6	6	6	6	6	6	6	6	6
SRM CASE AFT STIFFNESS T	0	0	0	0	0	0	0	1	1	1	2	3	3	3	3	3
SRM CASE CYLINDER OTHER	0	0	4	3	3	9	9	9	9	9	9	9	9	9	9	9
SRM CASE CYLINDER OTH SE	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM CASE CYLINDER OTH SE	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM CASE CYLINDER OTH SE	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM CASE CYLINDER OTH SE	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM NOZZLE COMPLIANCE RI	0	0	2	3	3	3	3	3	3	3	4	4	4	4	4	4
SRM NOZZLE OTHER PARTS	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM NOZZLE ELASTOMER	1	3	3	5	5	5	5	10	10	10	10	10	10	10	10	10
SRM NOZZLE BEARING SHIMS	0	0	1	2	2	3	3	3	3	3	3	3	3	3	3	3
SRM NOZZLE AFT END RING	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3
SRM NOZZLE FWD END RING	0	0	3	3	3	3	3	3	3	3	3	3	3	3	3	2
SRM IGNITER METAL PARTS	0	0	1	1	1	2	2	3	3	3	3	3	3	3	3	3
SRM PROPELLANT	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
SRM INSULATION AND LINER	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
SRM ELECTRICAL	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
SRM MISCELLANEOUS MATERI	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
DAC TVC NEW HARDWARE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INTGRTD ELCTRNC ASSMBLY	0	0	0	0	0	0	0	0	2	2	3	3	4	4	4	4
ALTITUDE SWITCH NEW	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2
FRUSTUM LOCATION AID	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	2
RF BEACON NEW	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2	2
RF BEACON ANTENNA NEW	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2
FLASHING LIGHT NEW	0	0	0	0	0	1	3	3	3	4	4	4	4	4	4	4
RATE GYRO NEW	0	0	0	0	0	0	2	2	2	7	7	7	7	7	5	5
CABLE REUSABLE NEW	0	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2
SENSORS NEW	0	0	0	2	2	2	5	5	5	5	5	5	5	5	5	4
RECOVERY BATTERY NEW	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
FRUSTUM BATTERY NEW	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22	24
CABLE THROUGHWAY NEW	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22
TVC ACTUATOR NEW	0	0	2	2	3	4	4	5	8	8	8	8	8	8	8	8
TVC POWER SUPPLY NEW	0	0	0	0	0	1	2	2	4	5	6	5	5	5	5	5
NOSE CAP NEW	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22	24
NOSE FRUSTUM NEW	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2
SEPARATION RING NEW	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22	24
FWD SKIRT NEW	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
FWD TUNNEL NEW	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
AFT TUNNEL NEW	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
REUSABLE STRUTS NEW	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
EXPENDABLE STRUTS NEW	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22
ET ATTACH RING NEW	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
AFT SKIRT NEW	0	0	0	0	2	2	2	2	3	3	3	3	3	3	3	3

Figure 47. (Continued).

06/26/78 15:27:18 DPA/EL82

NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE CONTD

SUBSYSTEM	FY1981 QTR1	FY1981 QTR2	FY1981 QTR3	FY1981 QTR4	FY1982 QTR1	FY1982 QTR2	FY1982 QTR3	FY1982 QTR4	FY1983 QTR1	FY1983 QTR2	FY1983 QTR3	FY1983 QTR4	FY1984 QTR1	FY1984 QTR2	FY1984 QTR3	FY1984 QTR4
THERMAL SHIELD NEW	4	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22
PILOT CHUTE	6	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22
DROGUE CHUTE	0	0	0	0	0	2	3	3	3	3	3	3	3	3	3	3
MAIN CHUTE	0	0	0	0	0	0	2	6	9	9	9	9	9	9	9	9
PLA PARACHUTE LOCATION A	0	0	0	0	0	0	8	8	8	8	8	8	8	8	8	8
MAIN PARACHUTE SUPPORT S	0	0	0	0	0	2	2	2	2	2	2	2	2	2	2	2
SUB SEPARATION MOTORS	64	32	64	64	80	80	80	80	112	128	144	144	160	176	176	192
SUB PYROTECHNICS	8	4	8	8	10	10	10	10	14	16	18	18	20	22	22	24

Figure 47. (Continued).

08/28/78 16:28:43 DPA/EL22

N E W H A R D W A R E
INCREMENT 2
D E L I V E R Y S C H E D U L E

SUBSYSTEM	FY1985 QTR1	FY1985 QTR2	FY1985 QTR3	FY1985 QTR4	FY1986 QTR1	FY1986 QTR2	FY1986 QTR3	FY1986 QTR4	FY1987 QTR1	FY1987 QTR2	FY1987 QTR3	FY1987 QTR4	FY1988 QTR1	FY1988 QTR2	FY1988 QTR3	FY1988 QTR4
SRM CASE AFT CYLINDER	6	6	6	6	6	3	3	3	3	3	3	3	3	3	3	3
SRM CASE FWD CYLINDER	6	6	6	6	4	4	4	4	4	4	4	4	4	4	4	4
SRM CASE AFT STIFFNESS T	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
SRM CASE CYLINDER OTHER	9	9	9	9	6	6	6	6	6	6	6	6	6	6	6	6
SRM CASE CYLINDER OTH SE	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1
SRM CASE CYLINDER OTH SE	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1
SRM CASE CYLINDER OTH SE	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1
SRM CASE CYLINDER OTH SE	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1
SRM NOZZLE COMPLIANCE RI	4	2	2	3	2	2	2	2	2	2	2	2	2	2	2	2
SRM NOZZLE OTHER PARTS	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1
SRM NOZZLE ELASTOMER	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
SRM NOZZLE BEARING SHIMS	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SRM NOZZLE AFT END RING	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SRM NOZZLE FWD END RING	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	[illegible]
SRM IGNITER METAL PARTS	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	[illegible]
SRM PROPELLANT	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24
SRM INSULATION AND LINER	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24
SRM ELECTRICAL	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24
SRM MISCELLANEOUS MATERI	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24
SRB TVC NEW HARDWARE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INTGRTD ELCTRNC ASSMBLY	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	3
ALTITUDE SWITCH NEW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
FRUSTUM LOCATION AID	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
RF BEACON NEW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
RF BEACON ANTENNA NEW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
FLASHING LIGHT NEW	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
RATE GYRO NEW	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
CABLE REUSABLE NEW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SENSORS NEW	4	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3
RECOVERY BATTERY NEW	22	24	28	24	26	26	26	24	26	28	26	28	30	30	28	24
FRUSTUM BATTERY NEW	26	24	25	25	26	24	25	28	26	28	30	30	28	24	26	28
CABLE THRUWAY NEW	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24	26
TVC ACTUATOR NEW	8	8	8	8	7	7	7	7	7	7	7	7	7	7	7	7
TVC POWER SUPPLY NEW	5	5	5	5	5	5	5	5	3	5	5	5	5	5	5	5
NOSE CAP NEW	26	24	26	26	26	24	26	28	26	28	30	30	28	24	26	28
NOSE FRUSTUM NEW	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SEPARATION RING NEW	26	24	28	26	28	24	26	28	26	28	30	30	28	24	26	28
FWD SKIRT NEW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FWD TUNNEL NEW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AFT TUNNEL NEW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
REUSABLE STRUTS NEW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EXPENDABLE STRUTS NEW	24	28	24	23	26	28	24	26	28	26	28	30	30	28	24	26
ET ATTACH RING NEW	1	1	1	1	1	1	1	1	1	2	2	2	1	1	1	1
AFT SKIRT NEW	3	3	3	3	3	3	3	3	3	3	5	5	5	5	3	3

Figure 47. (Continued).

08/28/78 15:28:46 DPA/EL22

N E W H A R D W A R E
INCREMENT 2
D E L I V E R Y S C H E D U L E C O N T D

S U B S Y S T E M	FY1985 QTR1	FY1985 QTR2	FY1985 QTR3	FY1985 QTR4	FY1986 QTR1	FY1986 QTR2	FY1986 QTR3	FY1986 QTR4	FY1987 QTR1	FY1987 QTR2	FY1987 QTR3	FY1987 QTR4	FY1988 QTR1	FY1988 QTR2	FY1988 QTR3	FY1988 QTR4
THERMAL SHIELD NEW	22	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24
PILOT CHUTE	24	26	24	26	26	26	24	26	28	26	28	30	30	28	24	26
DROGUE CHUTE	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4
MAIN CHUTE	9	9	9	9	9	12	12	12	12	12	12	12	12	12	12	12
PLA PARACHUTE LOCATION A	8	8	8	10	10	10	10	10	10	10	10	10	10	10	10	10
MAIN PARACHUTE SUPPORT S	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
SUB SEPARATION MOTORS	208	192	208	208	208	192	208	224	208	224	240	240	224	192	208	224
SUB PYROTECHNICS	26	24	26	26	26	24	26	28	26	28	30	30	28	24	26	28

Figure 47. (Continued).

03/23/78 15:30:03 DPA/EL28

NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE

SUBSYSTEM	FY1989 QTR1	QTR2	QTR3	QTR4	FY1990 QTR1	QTR2	QTR3	QTR4	FY1991 QTR1	QTR2	QTR3	QTR4	FY1992 QTR1	QTR2	QTR3	QTR4
SRP CASE AFT CYLINDER	3	3	3	3	3	3	3	3	3	1	0	0	0	0	0	0
SRM CASE FWD CYLINDER	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0
SRM CASE AFT STIFFNESS T	3	3	3	3	3	3	3	2	0	0	0	0	0	0	0	0
SRM CASE CYLINDER OTHER	6	6	6	6	6	6	6	6	6	6	3	0	0	0	0	0
SRM CASE CYLINDER OTH SE	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
SRM CASE CYLINDER OTH SE	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
SPM CASE CYLINDER OTH SE	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
SRM CASE CYLINDER OTH SE	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
SRM NOZZLE COMPLIANCE RI	2	2	2	2	2	2	2	2	2	2	2	0	0	0	0	0
SRM NOZZLE OTHER PARTS	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
SRM NOZZLE ELASTOMER	10	10	10	10	10	10	10	10	10	10	10	3	0	0	0	0
SRM NOZZLE BEARING SHIMS	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
SRM NOZZLE AFT END RING	2	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0
SRM NOZZLE FWD END RING	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
SRM IGNITER METAL PARTS	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
SRM PROPELLANT	26	28	23	23	23	30	28	23	23	28	26	26	26	10	2	0
SRM INSULATION AND LINER	26	28	29	23	28	30	28	23	28	28	26	26	26	10	2	0
SRM ELECTRICAL	26	23	28	28	28	33	28	28	28	28	26	26	26	10	2	0
SRP MISCELLANEOUS MATERI	26	28	28	28	28	30	28	26	28	28	26	26	26	10	2	0
BAC TVC NEW HARDWARE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
INTGRTD ELCTRNC ASSMBLY	3	3	3	3	3	3	3	3	3	1	0	0	0	0	0	0
ALTITUDE SWITCH NEW	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0	0
FRUSTUM LOCATION AID	2	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0
RF BEACON NEW	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0
RF BEACON ANTENNA NEW	2	2	2	2	2	2	1	0	0	0	0	0	0	0	0	0
FLASHING LIGHT NEW	4	4	4	4	4	4	4	4	4	4	1	0	0	0	0	0
RATE GYRO NEW	5	5	5	5	5	5	5	5	5	1	0	0	0	0	0	0
CABLE REUSABLE NEW	2	2	2	2	2	2	0	0	0	0	0	0	0	0	0	0
SENSORS NEW	3	[illegible]	3	3	3	3	3	3	3	3	0	0	0	0	0	0
RECOVERY BATTERY NEW	26	[illegible]	28	28	28	30	28	28	28	28	26	26	26	10	2	0
FRUSTUM BATTERY NEW	28	28	28	30	28	28	28	28	26	26	26	10	2	0	0	0
CABLE THROWAWAY NEW	28	23	28	28	30	28	28	28	28	26	26	26	10	2	0	0
TVC ACTUATOR NEW	7	7	7	7	7	7	7	7	[illegible]	0	0	0	0	0	0	0
TVC POWER SUPPLY NEW	5	5	5	5	5	5	5	5	5	5	3	0	0	0	0	0
NOSE CAP NEW	23	28	28	30	28	28	28	28	26	26	26	10	2	0	0	0
NOSE FRUSTUM NEW	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPARATION RING NEW	28	28	28	30	28	28	28	28	26	26	26	10	2	0	0	0
FWD SKIRT NEW	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
FWD TUNNEL NEW	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
AFT TUNNEL NEW	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
REUSABLE STRUTS NEW	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
EXPENDABLE STRUTS NEW	28	23	28	28	30	28	28	23	28	26	26	26	10	2	0	0
ET ATTACH RING NEW	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0
AFT SKIRT NEW	3	3	3	3	3	3	3	3	3	3	3	0	0	0	0	0

Figure 47. (Continued).

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NEW HARDWARE
INCREMENT 2
DELIVERY SCHEDULE CONTD

SUBSYSTEM	FY1989 QTR1	FY1989 QTR2	FY1989 QTR3	FY1989 QTR4	FY1990 QTR1	FY1990 QTR2	FY1990 QTR3	FY1990 QTR4	FY1991 QTR1	FY1991 QTR2	FY1991 QTR3	FY1991 QTR4	FY1992 QTR1	FY1992 QTR2	FY1992 QTR3	FY1992 QTR4
THERMAL SHIELD NEW	26	28	28	28	28	30	28	28	28	28	26	26	26	10	2	0
PILOT CHUTE	28	23	28	28	30	28	28	28	28	26	26	26	10	2	0	0
DROGUE CHUTE	4	4	4	4	4	4	4	4	4	4	0	0	0	0	0	0
MAIN CHUTE	12	12	12	12	12	12	12	12	12	12	11	0	0	0	0	0
PLA PARACHUTE LOCATION A	10	10	10	10	10	10	10	10	10	10	10	2	0	0	0	0
[illegible]IN PARACHUTE SUPPORT S	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
[illegible]B SEPARATION MOTORS & PYROTECHNICS	224	224	224	240	224	224	224	224	208	208	208	80	12	0	0	0
	28	28	28	30	28	28	28	28	26	26	26	10	2	0	0	0

Figure 47. (Concluded).

SUBSYSTEM	FY1977 QTR1	QTR2	QTR3	QTR4	FY1978 QTR1	QTR2	QTR3	QTR4	FY1979 QTR1	QTR2	QTR3	QTR4	FY1980 QTR1	QTR2	QTR3	QTR4
SRM CASE REFURB	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2
SRM NOZZLE REFURB	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2
SRM IGNITER REFURB	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2
INTEGRATED ELECTRONIC AS	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	5
ALTITUDE SWITCH DLM	0	0	0	0	0	0	0	0	0	0	1	2	1	1	2	3
FRUSTRUM LOCATION AID DL	0	0	0	0	0	0	0	0	0	0	1	2	0	1	3	3
RF BEACON DLM	0	0	0	0	0	0	0	0	0	0	1	1	1	3	2	2
RF BEACON ANTENNA DLM	0	0	0	0	0	0	0	0	0	0	1	2	0	3	2	2
FLASHING LIGHT DLM	0	0	0	0	0	0	0	0	0	0	1	2	1	2	2	2
RATE GYRO DLM	0	0	0	0	0	0	0	0	0	0	3	3	4	3	6	10
CABLE REUSABLE DLM	0	0	0	0	0	0	0	0	0	0	1	1	1	3	2	2
SENSORS DLM	0	0	0	0	0	0	0	0	0	0	0	3	2	0	2	3
ACTUATOR DLM	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
POWER SUPPLY DLM	0	0	0	0	0	0	0	0	0	0	0	0	2	3	1	5
NOSE FRUSTRUM DLM	0	0	0	0	0	0	0	0	0	0	1	2	1	1	2	2
FORWARD SKIRT	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	3
FORWARD TUNNEL DLM	0	0	0	0	0	0	0	0	0	0	1	1	2	2	1	2
AFT TUNNEL DLM	0	0	0	0	0	0	0	0	0	0	2	1	1	2	2	2
REUSABLE STRUTS BAC DLM	0	0	0	0	0	0	0	0	0	0	1	1	1	3	2	2
AFT SKIRT BAC REF	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	3
ET ATTACH RING BAC DLM	0	0	0	0	0	0	0	0	0	0	1	2	0	3	2	2
SATELLITE FLOATS BAC DLM	0	0	0	0	0	0	0	0	0	0	3	4	2	4	6	9

SUBSYSTEM	FY1981 QTR1	QTR2	QTR3	QTR4	FY1982 QTR1	QTR2	QTR3	QTR4	FY1983 QTR1	QTR2	QTR3	QTR4	FY1984 QTR1	QTR2	QTR3	QTR4
SRM CASE REFURB	4	4	4	6	8	6	5	10	10	9	10	12	13	16	19	17
SRM NOZZLE REFURB	4	4	4	6	8	5	6	10	10	9	10	12	13	16	19	17
SRM IGNITER REFURB	4	4	4	6	8	6	5	10	10	9	10	12	13	16	19	17
INTEGRATED ELECTRONIC AS	1	5	5	7	7	4	8	9	9	10	10	12	15	17	18	17
ALTITUDE SWITCH DLM	1	2	3	2	3	5	5	5	6	5	8	8	11	8	12	11
FRUSTRUM LOCATION AID DL	1	1	3	3	4	4	4	5	5	6	8	8	9	9	12	11
RF BEACON DLM	1	2	3	3	3	5	4	5	6	6	7	9	9	8	11	18
RF BEACON ANTENNA DLM	1	3	2	3	3	4	4	5	5	6	9	9	8	10	12	11
FLASHING LIGHT DLM	1	2	2	2	4	4	3	4	6	6	8	8	7	9	10	10
RATE GYRO DLM	3	6	8	8	9	15	15	14	16	15	22	25	33	26	33	36
CABLE REUSABLE DLM	1	3	1	4	4	3	5	4	6	7	6	9	8	1	11	12
SENSORS DLM	4	4	4	3	6	6	11	6	11	9	11	14	15	1.	17	20
ACTUATOR DLM	4	2	1	5	5	4	6	4	10	5	12	7	9	13	15	15
POWER SUPPLY DLM	2	4	4	6	6	6	6	7	9	9	10	13	15	16	19	18
NOSE FRUSTRUM DLM	1	2	3	3	2	5	4	4	6	6	8	9	8	10	12	12
FORWARD SKIRT	1	2	2	3	4	2	4	4	5	5	5	6	8	10	7	10
FORWARD TUNNEL DLM	1	3	2	3	4	4	5	5	5	6	7	10	9	11	10	13
AFT TUNNEL DLM	1	3	1	4	3	5	4	5	5	7	8	8	9	11	10	18
REUSABLE STRUTS BAC DLM	1	3	2	3	4	5	4	5	6	7	7	9	10	11	9	13
AFT SKIRT BAC REF	1	1	2	3	3	2	4	3	5	4	4	6	6	7	9	10
ET ATTACH RING BAC DLM	1	3	2	4	4	4	4	5	6	6	7	10	9	11	10	12
SATELLITE FLOATS BAC DLM	3	5	8	8	9	13	10	14	14	19	20	23	26	30	29	33

Figure 48. REF hardware increment 2 delivery schedule.

SUBSYSTEM	FY1985 QTR1	FY1985 QTR2	FY1985 QTR3	FY1985 QTR4	FY1986 QTR1	FY1986 QTR2	FY1986 QTR3	FY1986 QTR4	FY1987 QTR1	FY1987 QTR2	FY1987 QTR3	FY1987 QTR4	FY1988 QTR1	FY1988 QTR2	FY1988 QTR3	FY1988 QTR4
SRM CASE REFURB	20	21	22	24	26	23	26	25	23	26	27	25	25	28	27	26
SRM NOZZLE REFURB	20	21	21	26	25	23	26	25	23	26	27	25	26	28	27	26
SRM IGNITER REFURB	20	21	22	24	26	23	26	25	23	26	27	25	25	28	27	26
INTEGRATED ELECTRONIC AS	22	22	21	24	24	24	23	25	24	25	25	25	24	27	31	27
ALTITUDE SWITCH DLM	11	11	11	12	11	11	13	13	12	11	13	11	14	12	15	16
FRUSTRUM LOCATION AID DL	11	12	11	11	11	12	12	12	13	11	13	12	13	14	13	15
RF BEACON DLM	11	11	11	12	10	12	12	13	13	10	13	14	13	14	13	16
RF BEACON ANTENNA DLM	10	11	9	12	12	11	14	12	12	11	13	12	13	14	15	14
FLASHING LIGHT DLM	9	12	8	11	10	10	11	11	10	11	11	10	12	12	13	14
RATE GYRO DLM	33	35	30	37	34	34	37	37	37	35	36	34	41	39	41	46
CABLE REUSABLE DLM	10	12	10	12	11	11	13	13	12	12	11	12	13	14	15	15
SENSORS DLM	26	21	21	21	24	24	22	25	24	24	24	28	26	26	27	25
ACTUATOR DLM	17	17	17	23	22	20	22	23	22	24	21	24	26	22	26	27
POWER SUPPLY DLM	18	20	22	22	24	22	25	22	24	25	23	24	26	26	29	26
NOSE FRUSTRUM DLM	10	11	10	13	10	11	14	12	12	13	13	11	14	14	13	14
FORWARD SKIRT	11	11	10	12	12	12	12	13	13	12	12	13	14	15	15	13
FORWARD TUNNEL DLM	12	11	12	11	11	12	12	14	13	13	12	10	15	14	16	14
AFT TUNNEL DLM	12	11	11	11	10	12	12	13	12	13	13	11	14	14	15	15
REUSABLE STRUTS BAC DLM	11	12	11	11	12	11	13	13	12	13	13	12	14	14	15	16
AFT SKIRT BAC REF	9	10	10	11	11	11	12	11	11	11	11	11	14	12	13	13
ET ATTACH RING BAC DLM	13	10	12	11	10	12	13	13	14	12	13	11	14	14	14	15
SATELLITE FLOATS BAC DLM	31	28	31	31	32	34	36	33	34	33	33	34	36	38	37	38

SUBSYSTEM	FY1989 QTR1	FY1989 QTR2	FY1989 QTR3	FY1989 QTR4	FY1990 QTR1	FY1990 QTR2	FY1990 QTR3	FY1990 QTR4	FY1991 QTR1	FY1991 QTR2	FY1991 QTR3	FY1991 QTR4	FY1992 QTR1	FY1992 QTR2	FY1992 QTR3	FY1992 QTR4
SRM CASE REFURB	26	23	26	26	30	22	28	27	30	24	26	25	24	10	0	0
SRM NOZZLE REFURB	26	22	26	26	30	22	28	26	[illegible]	24	26	25	24	10	0	0
SRM IGNITER REFURB	26	23	26	26	30	22	28	27	30	24	26	25	24	10	0	0
INTEGRATED ELECTRONIC AS	24	23	26	26	26	26	26	30	24	27	23	25	24	26	5	0
ALTITUDE SWITCH DLM	13	12	13	13	13	13	13	15	12	13	13	12	[illegible]	0	0	0
FRUSTRUM LOCATION AID DL	14	12	12	11	11	13	13	15	15	13	11	13	5	0	0	0
RF BEACON DLM	13	12	12	12	12	13	14	14	14	13	12	13	6	0	0	0
RF BEACON ANTENN DLM	14	11	12	14	12	13	14	14	13	13	12	13	10	0	0	0
FLASHING LIGHT DLM	12	11	12	11	11	12	12	12	12	12	11	11	6	0	0	0
RATE GYRO DLM	40	37	37	41	38	37	42	45	37	40	39	37	16	0	0	0
CABLE REUSABLE DLM	13	11	12	12	14	13	12	14	14	13	12	12	7	0	0	0
SENSORS DLM	29	27	26	25	26	24	23	31	27	27	24	30	26	7	0	0
ACTUATOR DLM	28	27	22	21	28	24	26	25	28	25	23	23	24	24	10	0
POWER SUPPLY DLM	24	20	26	25	25	25	26	28	25	24	26	24	24	24	2	0
NOSE FRUSTRUM DLM	14	12	13	13	13	12	13	15	13	13	13	12	6	0	0	0
FORWARD SKIRT	13	12	13	13	14	13	15	14	13	14	14	13	13	12	2	0
FORWARD TUNNEL DLM	15	12	12	12	13	14	13	14	13	13	16	12	5	0	0	0
AFT TUNNEL DLM	14	13	13	11	14	13	13	15	13	14	13	12	6	0	0	0
REUSABLE STRUTS BAC DLM	13	13	13	12	13	14	13	15	13	14	13	13	6	0	0	0
AFT SKIRT BAC REF	11	11	12	13	12	11	14	12	12	12	13	12	12	11	2	0
ET ATTACH RING BAC DLM	14	12	12	11	14	14	12	15	13	13	14	14	4	0	0	0
SATELLITE FLOATS BAC DLM	38	36	33	33	38	36	38	43	38	37	33	37	15	0	0	0

Figure 48. (Concluded).

D. Annual Cost Program

All the SRB hardware delivery data, TFU's, learning curves, spread functions, and inflation rates are integrated into the ACP and a budget estimate results. A basic ACP description and flowchart is contained in Appendix E. The program is documented in detail in References 31, 32 and 33. Figures 45 through 48 along with the TFU and learning curve data from Figures 28 and 29 complete a set of ACP input data. The first output is a ranking of the WBS elements by percentage contribution to total program cost. Figure 49 illustrates this form of output. The SRM yearly and total cost is shown in Figure 50. In Figure 50 "NHW" means non-hardware, "NEW" means new hardware and "REF" means refurbishment. BAC costs are summarized in Figure 51. For WBS elements listed twice, the first is increment 2 costs and the second is increment 3 costs. The cost of new SRB hardware is presented in Figure 52 and refurbished hardware costs are presented in Figure 53. An ACP study of the SRB electronics and instrumentation costs is presented in Reference 34.

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RANKING BY COST OF EACH WBS BLOCK IN WHICH INPUT DATA WAS ENTERED

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RANK	BLOCK	SUBSYSTEM NAME	COST	PERCENT	CUMULATIVE COST	CUMULATIVE PERCENT
1	32	SRM PROPELLANT	1763864.48	33.90	1763864.48	33.90
2	20	SRM NOZZLE LABOR	927654.16	17.83	2691518.62	51.72
3	35	SRM MATERIAL FINISHING + INSPECTION	219435.82	4.22	2910954.44	55.94
4	33	SRM INSULATION AND LINER	182353.15	3.50	3093307.56	59.44
5	37	SRM MULTI ELEMENT SUPPORT	169914.70	3.27	3263222.25	62.71
6	7	SRM PLANNING + DIRECT TECH SUPPORT	135715.23	2.61	3398937.47	65.32
7	101	AFT SKIRT NEW	101683.80	1.95	3500621.25	67.27
8	110	SUB PYROTECHNICS	101666.16	1.95	3602287.41	69.22
9	50	TVC POWER SUPPLY NEW	89188.16	1.71	3691475.56	70.94
10	99	EXPENDABLE STRUTS NEW	88779.06	1.71	3780254.59	72.64
11	72	INTGRTD ELCTRNC ASSMBLY NEW	77007.23	1.48	3857261.81	74.12
12	183	SRB ASSEMBLY + CHECKOUT	74270.96	1.43	3931532.75	75.55
13	18	SRM CASE REFURB	72420.51	1.39	4003953.25	76.94
14	13	SRM CASE CYLINDER OTHER SEGMENTS	62048.94	1.19	4066002.19	78.14
15	109	SUB SEPARATION MOTORS	51306.59	.99	4117308.75	79.12
16	12	SRM CASE AFT CYLINDER	50586.31	.97	4167895.06	80.09
17	89	TVC ACTUATOR NEW	48620.50	.93	4216515.56	81.03
18	4	SRM PROJECT ENG. + INTEGRATION	47017.02	.90	4263532.56	81.93
19	3	SRM MANAGEMENT	44948.42	.86	4308480.94	82.80
20	11	SRM CASE FWD CYLINDER	43653.41	.84	4352134.31	83.63
21	106	MAIN CHUTE	39994.38	.77	4392128.69	84.40
22	190	SRB ETR TRANSPORTATION	38656.34	.74	4430785.00	85.15
23	158	SRB PROJECT MANAGEMENT	35138.39	.68	4465923.37	85.82
24	112	USBI REFURB	35010.18	.67	4500933.50	86.49
25	116	INTEGRATED ELECTRONIC ASSEMBLY DLM	32764.09	.63	4533697.56	87.12
26	171	SRB PROJECT ENGR + INTEGRATION	32627.70	.63	45[illegible]6325.25	87.75
27	23	SRM NOZZLE ELASTOMER	31664.97	.61	4597990.19	88.36
28	132	AFT SKIRT BAC REF	31341.33	.60	4629331.50	88.96
29	5	SRM SUPPORT EQPT + TOOLING MAINT.	30564.93	.59	4659896.37	89.55
30	173	SRB SAFETY.RELIABILITY + QUALASSUR	29491.38	.57	4689387.75	90.12
31	92	NOSE CAP NEW	29255.36	.56	4718643.06	90.68
32	14	SRM CASE CYLINDER OTH SEG FWD	28178.57	.54	4746821.62	91.22
33	16	SRM CASE CYLINDER OTH SEG AFT	26010.99	.50	4772832.56	91.72
34	15	SRM CASE CYLINDER OTH SEG ATT	23843.40	.46	4796675.94	92.18
35	22	SRM NOZZLE OTHER PARTS	23679.38	.46	4820355.31	92.63
36	134	FORWARD SKIRT	23052.83	.44	4843408.12	93.07
37	29	SRM IGNITER LABOR	21943.58	.42	4865351.69	93.50
38	34	SRM ELECTRICAL	21882.50	.42	4887234.12	93.92
39	178	SRB LOGISTICS SUPPORT	19884.17	.38	4907118.25	94.30
40	94	SEPARATION RING NEW	17080.23	.3[illegible]	4924198.44	94.63
41	93	NOSE FRUSTUM NEW	16048.94	.31	4940247.37	94.94
42	102	THERMAL SHIELD NEW	15760.68	.30	4956008.00	95.24
43	27	SRM NOZZLE REFURB	15266.03	.29	4971274.00	95.53
44	95	FWD SKIRT NEW	14788.16	.28	4986062.12	95.82
45	49	BAC TVC NEW HARDWARE	14697.75	.28	5000759.81	96.10
46	191	SRB WTR TRANSPORTATION	14659.36	.28	5015419.12	96.38
47	24	SRM NOZZLE BEARING SHIMS	14163.96	.27	5029583.06	96.65
48	133	NOSE FRUSTRUM DLM	13890.98	.27	5043474.00	96.92
49	165	SRB REFURB SUBASSY FAC OPS + MAINT	13716.37	.26	5057190.31	97.18
50	131	POWER SUPPLY DLM	13275.96	.26	5070466.25	97.44

Figure 49. Ranking by cost of each WBS block in which input data was entered.

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RANK	BLOCK	SUBSYSTEM NAME	COST	PERCENT	CUMULATIVE COST	CUMULATIVE PERCENT
51	9	SRM CASE LABOR	11723.74	.23	5082189.94	97.66
52	36	SRM MISCELLANEOUS MATERIALS	9172.52	.18	5091362.44	97.84
53	82	RATE GYRO NEW	9128.71	.18	5100491.12	98.02
54	25	SRM NOZZLE AFT END RING	8044.26	.15	5108535.37	98.17
55	105	DROGUE CHUTE	7996.33	.15	5116531.69	98.32
56	21	SRM NOZZLE COMPLIANCE RING	7718.96	.15	5124250.62	98.47
57	108	MAIN PARACHUTE SUPPORT STRUCTURE	7511.52	.14	5131762.12	98.62
58	26	SRM NOZZLE FWD END RING	7434.55	.14	5139196.62	98.76
59	107	PLA PARACHUTE LOCATION AID	7148.00	.14	5146344.62	98.90
60	100	ET ATTACH RING NEW	6685.25	.13	5153029.87	99.02
61	87	CABLE THROWAWAY NEW	6567.58	.13	5159597.44	99.15
62	130	ACTUATOR DLM	5170.41	.10	5164767.81	99.25
63	98	REUSABLE STRUTS NEW	4074.12	.08	5168841.87	99.33
64	83	CABLE REUSABLE NEW	3351.81	.08	5172793.62	99.40
65	31	SRM IGNITER REFURB	3886.22	.07	5176679.81	99.48
66	17	SRM CASE CYLINDER OTH SEG JT HOUR	3196.05	.06	5179875.81	99.54
67	126	RATE GYRO DLM	2932.03	.06	5182807.81	99.60
68	127	CABLE REUSABLE DLM	2854.78	.05	5185662.56	99.65
69	85	RECOVERY BATTERY NEW	2505.35	.05	5188167.87	99.70
70	30	SRM IGNITER METAL PARTS	1942.80	.04	5190110.62	99.74
71	12	SRM CASE AFT STIFFNESS TEES	1726.81	.03	5191837.37	99.77
72	78	FRUSTUM LOCATION AID	1338.79	.03	5193176.12	99.80
73	104	PILOT CHUTE	1242.73	.02	5194418.81	99.82
74	141	SATELLITE FLOATS BAC DLM	1218.66	.02	5195637.44	99.84
75	96	FWD TUNNEL NEW	1091.75	.02	5196729.19	99.86
76	139	ET ATTACH RING BAC DLM	941.62	.02	5197670.75	99.88
77	137	REUSABLE STRUTS BAC DLM	888.40	.02	5198559.12	99.90
78	86	FRUSTUM BATTERY NEW	805.12	.02	5199364.19	99.92
79	97	AFT TUNNEL NEW	752.40	.01	5200116.56	99.93
80	122	FRUSTRUM LOCATION AID DLM	526.67	.01	5200643.19	99.94
81	77	ALTITUDE SWITCH NEW	496.36	.01	5201139.50	99.95
82	84	SENSORS NEW	457.79	.01	5201597.25	99.96
83	135	FORWARD TUNNEL DLM	410.17	.01	5202007.37	99.97
84	79	RF BEACON NEW	394.44	.01	5202401.81	99.97
85	121	ALTITUDE SWITCH DLM	335.83	.01	5202737.62	99.98
86	81	FLASHING LIGHT NEW	331.93	.01	5203069.50	99.99
87	136	AFT TUNNEL DLM	263.58	.01	5203333.06	99.99
88	123	RF BEACON DLM	203.20	.00	5203536.25	100.00
89	128	SENSORS DLM	138.17	.00	5203674.37	100.00
90	125	FLASHING LIGHT DLM	62.31	.00	5203736.62	100.00
91	80	RF BEACON ANTENNA NEW	19.06	.00	5203755.69	100.00
92	124	RF BEACON ANTENNA DLM	13.13	.00	5203768.81	100.00

TOTAL COST +5203770.56

Figure 49. (Concluded).

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WBS SUMMARY TABLE 2
SOLID ROCKET MOTOR

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ANNUAL SUMMARY		FY1977	FY1978	FY1979	FY1980	FY1981	FY1982	FY1983	FY1984
SRM MANAGEMENT	NHW	.00	.00	.00	143.17	715.25	1148.58	1867.64	2920.60
SRM PROJECT ENG. + INTEG	NHW	.00	.00	.00	149.76	748.16	1201.44	1953.59	3064.32
SRM SUPPORT EQPT + TOOLI	NHW	.00	.00	.00	97.35	486.37	781.04	1269.99	1992.06
SRM PLANNING + DIRECT TE	NHW	.00	.00	.00	432.27	2159.58	3467.98	5639.06	8845.20
SRM CASE LABOR	NHW	.00	.00	.00	24.07	370.58	462.55	597.72	893.15
SRM CASE AFT CYLINDER	NEW	.00	.00	276.73	2357.77	5037.69	6723.54	6990.62	6080.52
SRM CASE FWD CYLINDER	NEW	.00	.00	586.20	2129.99	4129.64	4836.52	4903.76	4561.50
SRM CASE AFT STIFFNESS T	NEW	.00	.00	.00	10.77	59.50	131.39	196.14	209.56
SRM CASE CYLINDER OTHER	NEW	.00	.00	.00	1479.60	5600.61	6436.16	6703.20	6896.10
SRM CASE CYLINDER OTH SE	NEW	.00	.00	.00	437.56	2147.38	3820.25	4183.85	4383.68
SRM CASE CYLINDER OTH SE	NEW	.00	.00	.00	370.24	1817.02	3232.52	3540.18	3709.26
SRM CASE CYLINDER OTH SE	NEW	.00	.00	.00	403.90	1982.20	3526.38	3862.02	4046.47
SRM CASE CYLINDER OTH SE	NEW	.00	.00	.00	42.85	220.76	418.37	467.86	501.48
SRM CASE REFURB	REF	.00	.00	.00	765.36	1471.78	2220.30	3058.79	4797.42
SRM NOZZLE LABOR	NHW	.00	.00	.00	2003.78	15458.53	24430.14	37753.10	60119.34
SRM NOZZLE COMPLIANCE RI	NEW	.00	.00	.00	.00	500.41	761.93	967.50	1034.56
SRM NOZZLE OTHER PARTS	NEW	.00	.00	.00	29.04	1202.19	2955.65	3418.28	3546.32
SRM NOZZLE ELASTOMER	NEW	.00	.00	6.91	336.65	1144.23	2217.53	2732.38	2837.96
SRM NOZZLE BEARING SHIMS	NEW	.00	.00	.00	17.20	1154.23	1998.62	2065.56	1863.21
SRM NOZZLE AFT END RING	NEW	.00	.00	.00	24.22	828.29	942.38	973.49	800.69
SRM NOZZLE FWD END RING	NEW	.00	.00	.00	24.22	828.29	942.38	973.49	798.56
SRM NOZZLE REFURB	REF	.00	.00	.00	161.54	310.65	468.92	645.62	1012.59
SRM IGNITER LABOR	NHW	.00	.00	.00	18.22	369.33	580.21	849.94	1403.81
SRM IGNITER METAL PARTS	NEW	.00	.00	.00	.00	85.75	235.98	283.45	295.78
SRM IGNITER REFURB	REF	.00	.00	.00	41.07	78.98	119.15	164.14	257.44
SRM PROPELLANT	NEW	.00	.00	.00	3836.44	30875.46	48644.37	77640.54	118581.13
SRM INSULATION AND LINER	NEW	.00	.00	.00	1392.32	4357.57	6188.43	10130.83	14024.25
SRM ELECTRICAL	NEW	.00	.00	.00	178.10	546.53	765.30	1240.41	1703.23
SRM MATERIAL FINISHING +	NHW	.00	.00	.00	865.22	4337.80	6613.88	10162.44	15299.78
SRM MISCELLANEOUS MATERI	NEW	.00	.00	.00	.00	131.84	231.52	345.31	576.09
SRM MULTI ELEMENT SUPPOR	NHW	.00	.00	.00	.00	2202.83	3529.48	5533.01	9695.59
TOTAL		.00	.00	869.84	17772.78	91367.43	140026.88	201122.93	286838.53

Figure 50. WBS summary table 2 - solid rocket motor.

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WBS SUMMARY TABLE 2
SOLID ROCKET MOTOR

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ANNUAL SUMMARY		FY1985	FY1986	FY1987	FY1988	FY1989	FY1990	FY1991	FY1992
SRM MANAGEMENT	NHW	3840.43	4301.22	4930.53	5318.82	5714.42	6283.51	6095.67	1659.69
SRM PROJECT ENG. + INTEG	NHW	4017.17	4499.17	5157.44	5563.60	5977.40	6572.68	6376.20	1736.07
SRM SUPPORT EQPT + TOOLI	NHW	2611.49	2924.03	3352.76	3616.80	3805.80	4272.79	4145.06	1128.59
SRM PLANNING + DIRECT TE	NHW	11535.61	12923.02	14887.02	16059.41	17253.85	18972.14	10405.00	5011.19
SRM CASE LABOR	NHW	1033.02	1143.63	1193.61	1302.17	1267.37	1380.56	1369.29	635.24
SRM CASE AFT CYLINDER	NEW	4037.17	4150.54	4423.72	4717.23	3414.09	1673.69	.00	.00
SRM CASE FWD CYLINDER	NEW	4034.63	4003.54	4202.03	4540.46	3559.89	2075 [illegible]	.00	.00
SRM CASE AFT STIFFNESS T	NEW	233.26	232.62	246.55	239.73	150.10	3[illegible]	.00	.00
SRM CASE CYLINDER OTHER	NEW	5723.22	5205.53	5628.89	5993.63	6303.13	5128.[illegible]	770.45	.00
SRM CASE CYLINDER OTH SE	NEW	3333.74	1833.94	1751.31	1870.10	1997.39	1769.79	352.58	.00
SRM CASE CYLINDER OTH SE	NEW	3072.16	1551.80	1481.88	1582.39	1600.10	1497.52	298.34	.00
SRM CASE CYLINDER OTH SE	NEW	3331.45	1692.87	1615.60	1725.24	1843.74	1633.65	325.46	.00
SRM CASE CYLINDER OTH SE	NEW	421.11	214.55	205.85	220.64	235.60	210.15	41.92	.00
SRM CASE REFURB	REF	6405.99	7442.47	7711.76	8371.69	8310.15	9207.19	9473.52	3183.00
SRM NOZZLE LABOR	NHW	70133.30	80254.15	93853.95	103223.08	114614.75	127084.54	123237.30	41437.24
SRM NOZZLE COMPLIANCE RI	NEW	620.91	603.84	633.44	679.02	722.72	763.70	422.93	.00
SRM NOZZLE OTHER PARTS	NEW	3653.62	1627.48	1337.66	1403.86	1503.74	1697.76	1070.79	.00
SRM NOZZLE ELASTOMER	NEW	2973.03	3136.64	3316.32	3513.24	3723.95	3961.94	1755.61	.00
SRM NOZZLE BEARING SHIMS	NEW	1517.04	1607.46	1705.93	1703.89	445.74	.00	.00	.00
SRM NOZZLE AFT END RING	NEW	718.09	761.52	808.68	853.65	914.60	332.64	.00	.00
SRM NOZZLE FWD END RING	NEW	719.13	732.48	839.57	577.71	459.64	477.99	63.08	.00
SRM NOZZLE REFURB	REF	1383.05	1555.16	1627.72	1782.99	1736.59	1824.93	1999.29	671.97
SRM IGNITER LABOR	NHW	1052.28	2034.26	2235.26	2595.17	2611.07	2324.12	2970.86	1399.04
SRM IGNITER METAL PARTS	NEW	311.30	147.36	117.40	125.35	133.87	143.00	63.57	.00
SRM IGNITER REFURB	REF	343.81	393.38	413.83	449.24	445.94	454.08	508.37	170.81
SRM PROPELLANT	NEW	154124.35	163912.87	193836.82	205326.79	225523.56	246249.15	245841.76	41492.47
SRM INSULATION AND LINER	NEW	17019.94	18083.93	20302.30	20555.59	23103.46	24252.25	21255.90	1181.38
SRM ELECTRICAL	NEW	2053.87	2172.24	2438.40	2451.18	2747.82	2877.87	2517.74	139.82
SRM MATERIAL FINISHING +	NHW	19521.85	21163.61	24285.29	25279.25	27401.30	29769.48	29802.87	5133.07
SRM MISCELLANEOUS MATERI	NEW	759.35	863.72	981.07	1033.47	1148.17	1274.63	1293.69	478.65
SRM MULTI ELEMENT SUPPOR	NHW	13565.69	15765.58	17232.48	20688.31	20168.52	23249.31	24030.56	14333.35
TOTAL		355201.51	380178.37	432419.15	453494.30	489206.34	528102.75	509293.78	119761.67

Figure 50. (Continued).

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UBS SUMMARY TABLE 2
SOLID ROCKET MOTOR
COSTS FOR FY1977 THROUGH FY1992

SRM MANAGEMENT	NHU	44948.42
SRM PROJECT ENG. + INTEG	NHU	47017.02
SRM SUPPORT EQPT + TOOLI	NHU	38564.93
SRM PLANNING + DIRECT TE	NHU	135715.23
SRM CASE LABOR	NHU	11723.74
SRM CASE AFT CYLINDER	NEU	50586.31
SRM CASE FWD CYLINDER	NEU	43653.41
SRM CASE AFT STIFFNESS T	NEU	1726.81
SRM CASE CYLINDER OTHER	NEU	62048.94
SRM CASE CYLINDER OTH SE	NEU	28178.57
SRM CASE CYLINDER OTH SE	NEU	23843.40
SRM CASE CYLINDER OTH SE	NEU	26010.99
SRM CASE CYLINDER OTH SE	NEU	3196.05
SPM CASE REFURB	REF	72420.51
SRM NOZZLE LABOR	NHU	927654.16
SRM NOZZLE COMPLIANCE RI	NEU	7718.96
SRM NOZZLE OTHER PARTS	NEU	23679.38
SRM NOZZLE ELASTOMER	NEU	31664.97
SRM NOZZLE BEARING SHIMS	NEU	14163.96
SRM NOZZLE AFT END RING	NEU	8044.26
SRM NOZZLE FWD END RING	NEU	7434.55
SRM NOZZLE REFURB	REF	15266.03
SRM IGNITER LABOR	NHU	21943.58
SRM IGNITER METAL PARTS	NEU	1942.80
SRM IGNITER REFURB	REF	3886.22
SRM PROPELLANT	NEU	1763864.48
SRM INSULATION AND LINER	NEU	182353.15
SRM ELECTRICAL	NEU	21882.50
SRM MATERIAL FINISHING +	NHU	219435.82
SRM MISCELLANEOUS MATERI	NEU	9172.52
SRM MULTI ELEMENT SUPPOR	NHU	169914.70
TOTAL COST FOR FY1977 THROUGH FY1992 FOR UBS SUMMARY TABLE 2		4011656.19

Figure 50. (Concluded).

ANNUAL SUMMARY		FY1977	FY1978	FY1979	FY1980	FY1981	FY1982	FY1983	FY1984
SRB FLIGHT HARDWARE	NEW	.00	11.33	231.55	4370.29	15129.01	40349.24	65005.54	71126.45
SRB FLIGHT HARDWARE	NEW	.00	.00	.00	.00	.00	597.47	1313.27	1740.03
SRB PROJECT MANAGEMENT	NHW	.00	138.24	453.58	735.46	875.85	289.44	.00	.00
SRB PROJECT MANAGEMENT	NHW	.00	.00	.00	.00	116.79	1595.11	2469.63	2847.10
SRB REFURB SUBASSY FAC O	NHW	.00	.00	.00	170.64	266.76	109.08	.00	.00
SRB REFURB SUBASSY FAC O	NHW	.00	.00	.00	.00	17.28	588.50	1003.22	1075.31
SRB PROJECT ENGR + INTEG	NHW	.00	105.74	357.48	597.23	711.70	273.24	.00	.00
SRB PROJECT ENGR + INTEG	NHW	.00	.00	.00	.00	95.60	1404.58	2315.40	2481.79
SRB SAFETY RELIABILITY +	NHW	.00	74.51	149.03	227.88	237.57	73.43	.00	.00
SRB SAFETY RELIABILITY +	NHW	.00	.00	.00	.00	559.49	768.05	1075.40	1695.20
SRB LOGISTICS SUPPORT	NHW	.00	17.28	292.68	336.96	433.54	158.75	.00	.00
SRB LOGISTICS SUPPORT	NHW	.00	.00	.00	.00	.00	853.86	1419.89	1521.92
SRB ASSEMBLY + CHECKOUT	NHW	.00	.00	.00	.00	1513.45	1590.29	.00	.00
SRB ASSEMBLY + CHECKOUT	NHW	.00	.00	.00	.00	.00	567.86	3096.71	5011.58
USBI REFURB	NHW	.00	.00	94.49	389.78	703.55	739.27	.00	.00
USBI REFURB	NHW	.00	.00	.00	.00	.00	263.98	1439.55	2329.70
DEPOT LEVEL MAINTENANCE	REF	.00	.00	245.97	2531.80	2901.23	4370.55	6486.52	9811.86
TOTAL		.00	427.10	1824.77	9410.04	23567.81	54590.69	83625.14	99440.94

ANNUAL SUMMARY		FY1985	FY1986	FY1987	FY1988	FY1989	FY1990	FY1991	FY1992
SRB FLIGHT HARDWARE	NEW	76140.44	81515.72	91635.37	87375.44	90092.25	86560.41	44245.47	1569.78
SRB FLIGHT HARDWARE	NEW	1445.94	1507.26	1578.04	1651.06	1613.43	871.23	.00	.00
SRB PROJECT MANAGEMENT	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB PROJECT MANAGEMENT	NHW	2837.31	3041.20	3259.74	3493.98	3745.05	4014.17	4302.62	1123.12
SRB REFURB SUBASSY FAC O	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB REFURB SUBASSY FAC O	NHW	1152.59	1235.41	1324.18	1419.34	1521.33	1630.65	1747.83	456.24
SRB PROJECT ENGR + INTEG	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB PROJECT ENGR + INTEG	NHW	2560.13	2851.28	3056.17	3275.78	3511.18	3763.49	4033.93	1052.99
SRB SAFETY RELIABILITY +	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB SAFETY RELIABILITY +	NHW	2274.30	2614.25	2850.24	3360.18	3330.85	3302.21	3947.27	2451.51
SRB LOGISTICS SUPPORT	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB LOGISTICS SUPPORT	NHW	1631.28	1748.50	1874.15	2008.82	2153.18	2307.90	2473.74	645.73
SRB ASSEMBLY + CHECKOUT	NHW	.00	.00	.00	.00	.00	.00	.00	.00
SRB ASSEMBLY + CHECKOUT	NHW	6535.93	7137.05	7530.77	8608.28	8278.63	9308.88	9421.84	5539.71
USBI REFURB	NHW	.00	.00	.00	.00	.00	.00	.00	.00
USBI REFURB	NHW	3033.32	3341.00	3500.78	4038.87	3348.44	4327.36	4379.88	2575.21
DEPOT LEVEL MAINTENANCE	REF	11674.17	12589.36	12945.66	14945.28	13913.30	15389.48	15311.43	7017.53
TOTAL		109390.39	117731.03	129555.10	133257.04	132007.64	131975.77	93564.01	22431.81

Figure 51. WBS summary table 3 - solid rocket booster subsystems (BAC).

WBS SUMMARY TABLE 3
MIPS) SOLID ROCKET BOOSTER SUBSYSTEMS (BAC)
COSTS FOR FY1977 THROUGH FY1992

SRB FLIGHT HARDWARE	NEW	756058.27
SRB FLIGHT HARDWARE	NEW	12317.73
SRB PROJECT MANAGEMENT	NHW	2492.57
SRB PROJECT MANAGEMENT	NHW	32645.82
SRB REFURB SUBASSY FAC O	NHW	546.48
SRB REFURB SUBASSY FAC O	NHW	13169.89
SRB PROJECT ENGR + INTEG	NHW	2125.39
SRB PROJECT ENGR + INTEG	NHW	30502.31
SRB SAFETY RELIABILITY +	NHW	762.42
SRB SAFETY RELIABILITY +	NHW	28728.96
SRB LOGISTICS SUPPORT	NHW	1245.21
SRB LOGISTICS SUPPORT	NHW	18638.96
SRB ASSEMBLY + CHECKOUT	NHW	3103.74
SRB ASSEMBLY + CHECKOUT	NHW	71167.22
USBI REFURB	NHW	1927.08
USBI REFURB	NHW	33083.09
DEPOT LEVEL MAINTENANCE	REF	130284.13
TOTAL COST FOR FY1977 THROUGH FY1992 FOR WBS SUMMARY TABLE 3		1138799.20

Figure 51. (Concluded).

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WBS SUMMARY TABLE 4
SRB NEW HARDWARE

ANNUAL SUMMARY		FY1977	FY1978	FY1979	FY1980	FY1981	FY1982	FY1983	FY1984
INTGRTD ELCTRNC ASSMBLY	NEW	.00	.00	.00	.00	199.32	4791.09	9048.00	9701.99
ALTITUDE SWITCH NEW	NEW	.00	.00	.00	.00	.00	23.47	62.54	63.06
FRUSTUM LOCATION AID	NEW	.00	.00	.00	.00	14.64	124.88	175.07	173.63
RF BEACON NEW	NEW	.00	.00	.00	.00	.00	17.69	37.15	52.34
RF BEACON ANTENNA NEW	NEW	.00	.00	.00	.00	.00	.26	1.40	1.94
FLASHING LIGHT NEW	NEW	.00	.00	.00	.00	.00	21.76	33.99	33.78
RATE GYRO NEW	NEW	.00	.00	.00	.00	46.52	656.46	1290.79	981.91
CABLE REUSABLE NEW	NEW	.00	.00	.00	.00	.00	109.05	444.56	523.73
SENSORS NEW	NEW	.00	.00	.00	.00	16.51	56.06	57.95	50.96
RECOVERY BATTERY NEW	NEW	.00	.00	.00	25.19	89.69	110.77	157.54	208.45
FRUSTUM BATTERY NEW	NEW	.00	.00	.00	22.90	31.55	40.25	60.23	73.55
CABLE THROWAWAY NEW	NEW	.00	.00	.00	130.88	239.90	303.61	455.39	576.83
TVC ACTUATOR NEW	NEW	.00	.00	.00	.00	838.14	3039.75	5616.07	5482.55
TVC POWER SUPPLY NEW	NEW	.00	.00	.00	.00	.00	2675.59	9604.63	9129.96
NOSE CAP NEW	NEW	.00	.00	.00	456.35	804.81	1133.67	1852.06	2455.68
NOSE FRUSTUM NEW	NEW	.00	.00	.00	.00	298.86	2324.48	2170.59	2090.91
SEPARATION RING NEW	NEW	.00	.00	.00	500.03	666.66	856.66	1282.84	1560.53
FWD SKIRT NEW	NEW	.00	.00	.00	.00	281.64	1522.79	1560.13	1523.18
FWD TUNNEL NEW	NEW	.00	.00	.00	.00	6.65	109.28	110.27	108.25
AFT TUNNEL NEW	NEW	.00	.00	.00	.00	16.90	76.40	70.80	70.19
REUSABLE STRUTS NEW	NEW	.00	.00	.00	.00	.00	136.95	382.96	390.36
EXPENDABLE STRUTS NEW	NEW	.00	.00	.00	530.44	2010.01	2883.24	4647.10	6587.88
ET ATTACH RING NEW	NEW	.00	.00	.00	.00	.00	389.63	693.61	684.13
AFT SKIRT NEW	NEW	.00	.00	.00	.00	4335.04	8826.77	9576.09	9345.64
THERMAL SHIELD NEW	NEW	.00	.00	.00	51.39	426.53	578.92	823.00	1187.06
PILOT CHUTE	NEW	.00	.00	.00	9.27	32.13	44.38	70.08	96.47
DROGUE CHUTE	NEW	.00	.00	.00	.00	.00	541.77	648.47	652.47
MAIN CHUTE	NEW	.00	.00	.00	.00	.00	1718.51	3364.67	3318.01
PLA PARACHUTE LOCATION A	NEW	.00	.00	.00	.00	.00	396.81	589.39	587.33
MAIN PARACHUTE SUPPORT S	NEW	.00	.00	.00	.00	64.10	799.70	902.42	954.68
SRB SEPARATION MOTORS	NEW	.00	.00	.00	630.39	1243.45	1812.32	3048.84	4147.00
SRB PYROTECHNICS	NEW	.00	.00	77.59	1333.97	2403.18	3753.84	6166.93	8312.03
DAC TVC NEW HARDWARE	NEW	.00	11.33	153.96	679.48	1062.80	472.45	.00	.00
DAC TVC NEW HARDWARE	NEW	.00	.00	.00	.00	.00	597.47	1313.27	1740.03
TOTAL		.00	11.33	231.55	4370.29	15129.01	40946.72	66318.81	72866.48

Figure 52. WBS summary table 4 - SRB new hardware.

MIPS)

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UBS SUMMARY TABLE 4
SRB NEW HARDWARE

ANNUAL SUMMARY		FY1985	FY1986	FY1987	FY1988	FY1989	FY1990	FY1991	FY1992
INTGRTD ELCTRNC ASSMBLY	NEW	9912.80	10271.48	10276.27	8798.71	8939.06	4832.50	236.03	.00
ALTITUDE SWITCH NEW	NEW	63.66	65.38	67.79	70.71	74.07	5.68	.00	.00
FRUSTUM LOCATION AID	NEW	176.91	182.58	189.87	198.45	182.77	.00	.00	.00
RF BEACON NEW	NEW	52.39	53.59	55.43	57.73	60.40	7.71	.00	.00
RF BEACON ANTENNA NEW	NEW	2.68	2.71	2.78	2.88	3.01	1.40	.00	.00
FLASHING LIGHT NEW	NEW	34.18	35.14	36.46	38.05	39.87	41.89	16.83	.00
RATE GYRO NEW	NEW	958.89	990.93	1031.37	1078.63	1131.95	909.99	51.28	.00
CABLE REUSABLE NEW	NEW	524.24	536.27	554.70	577.69	604.41	77.17	.00	.00
SENSORS NEW	NEW	48.08	50.01	40.89	41.42	43.74	46.25	5.93	.00
RECOVERY BATTERY NEW	NEW	241.34	246.20	270.77	265.98	285.22	297.00	270.29	36.91
FRUSTUM BATTERY NEW	NEW	78.57	81.55	89.24	86.43	94.47	94.16	51.85	.37
CABLE THROWAWAY NEW	NEW	640.10	651.24	727.63	691.90	761.67	774.67	530.10	23.66
TVC ACTUATOR NEW	NEW	5551.55	5007.59	5213.93	5454.21	5724.82	6024.20	667.69	.00
TVC POWER SUPPLY NEW	NEW	9173.91	9400.35	9732.91	10142.59	10616.36	11148.08	7563.78	.00
NOSE CAP NEW	NEW	2752.56	2945.40	3396.22	3272.35	3697.25	3783.70	2635.56	29.75
NOSE FRUSTUM NEW	NEW	2088.30	2122.67	2180.38	2255.42	517.32	.00	.00	.00
SEPARATION RING NEW	NEW	1662.67	1745.25	1897.56	1869.35	2034.09	2021.94	974.30	3.95
FWD SKIRT NEW	NEW	1533.37	1567.26	1616.70	1678.07	1749.54	1546.93	208.56	.00
FWD TUNNEL NEW	NEW	109.41	112.17	116.02	120.69	126.08	132.13	40.79	.00
AFT TUNNEL NEW	NEW	71.25	73.24	75.89	79.03	82.63	86.65	49.44	.00
REUSABLE STRUTS NEW	NEW	406.36	426.58	449.68	475.85	504.34	535.33	305.52	.00
EXPENDABLE STRUTS NEW	NEW	8160.81	8708.16	10055.46	10070.09	11225.38	11534.14	11036.91	929.43
ET ATTACH RING NEW	NEW	697.23	793.74	1222.28	773.49	814.18	616.[illegible]	.00	.00
AFT SKIRT NEW	NEW	9406.25	10501.01	14703.33	10840.70	10552.86	10627.06	2963.05	.00
THERMAL SHIELD NEW	NEW	1453.09	1531.67	1707.90	1754.77	1860.37	1995.76	1963.96	426.28
PILOT CHUTE	NEW	116.60	122.72	140.05	138.45	153.68	161.70	146.21	12.94
DROGUE CHUTE	NEW	671.31	899.15	964.44	1008.85	1059.68	1116.33	433.87	.00
MAIN CHUTE	NEW	3476.49	4576.18	4835.24	5050.59	5299.82	5579.17	2775.69	.00
PLA PARACHUTE LOCATION A	NEW	658.68	776.43	807.84	845.53	888.49	936.26	661.24	.00
MAIN PARACHUTE SUPPORT S	NEW	1014.16	1079.65	1150.86	1227.85	318.11	.00	.00	.00
SUB SEPARATION MOTORS	NEW	4832.99	5167.58	6015.21	5857.31	6668.45	6881.81	4950.20	51.05
SUB PYROTECHNICS	NEW	9539.55	10787.86	12009.66	12551.65	14058.20	14343.85	6280.42	57.45
BAC TVC NEW HARDWARE	NEW	.00	.00	.00	.00	.00	.00	.00	.00
BAC TVC NEW HARDWARE	NEW	1445.94	1507.26	1578.04	1651.06	1613.43	871.23	.00	.00
TOTAL		77586.39	83022.98	93213.42	89026.50	91705.69	87431.64	44945.47	1569.78

Figure 52. (Continued).

UBS SUMMARY TABLE 4
RIPS) SRB NEW HARDWARE
COSTS FOR FY1977 THROUGH FY1992

INTGRTD ELCTRNC ASSMBLY	NEW	77007.23
ALTITUDE SWITCH NEW	NEW	496.36
FRUSTUM LOCATION AID	NEW	1338.79
RF BEACON NEW	NEW	394.44
RF BEACON ANTENNA NEW	NEW	19.06
FLASHING LIGHT NEW	NEW	331.93
RATE GYRO NEW	NEW	9128.71
CABLE REUSABLE NEW	NEW	3951.81
SENSORS NEW	NEW	457.79
RECOVERY BATTERY NEW	NEW	2505.35
FRUSTUM BATTERY NEW	NEW	805.12
CABLE THROWAWAY NEW	NEW	6567.58
TVC ACTUATOR NEW	NEW	48620.50
TVC POWER SUPPLY NEW	NEW	89188.16
NOSE CAP NEW	NEW	29255.36
NOSE FRUSTUM NEW	NEW	16048.94
SEPARATION RING NEW	NEW	17080.23
FWD SKIRT NEW	NEW	14783.16
FWD TUNNEL NEW	NEW	1091.75
AFT TUNNEL NEW	NEW	752.40
REUSABLE STRUTS NEW	NEW	4074.12
EXPENDABLE STRUTS NEW	NEW	88779.06
ET ATTACH RING NEW	NEW	6685.25
AFT SKIRT NEW	NEW	101683.80
THERMAL SHIELD NEW	NEW	15760.68
PILOT CHUTE	NEW	1242.73
DROGUE CHUTE	NEW	7996.33
MAIN CHUTE	NEW	39994.38
PLA PARACHUTE LOCATION A	NEW	7148.00
MAIN PARACHUTE SUPPORT S	NEW	7511.52
SUB SEPARATION MOTORS	NEW	51306.59
SUB PYROTECHNICS	NEW	101556.16
DAC TVC NEW HARDWARE	NEW	2380.02
BAC TVC NEW HARDWARE	NEW	12317.73
TOTAL COST FOR FY1977 THROUGH FY1992 FOR UBS SUMMARY TABLE 4		768376.03

Figure 52. (Concluded).

ANNUAL SUMMARY		FY1977	FY1978	FY1979	FY1980	FY1981	FY1982	FY1983	FY1984
INTEGRATED ELECTRONIC AS	REF	.00	.00	.00	646.00	809.81	1120.44	1529.26	2297.57
ALTITUDE SWITCH DLM	REF	.00	.00	3.73	6.77	6.90	14.32	19.08	29.39
FRUSTRUM LOCATION AID DL	REF	.00	.00	5.90	10.76	10.96	21.44	31.78	45.60
RF BEACON DLM	REF	.00	.00	1.59	4.76	4.67	8.14	12.51	16.95
RF BEACON ANTENNA DLM	REF	.00	.00	.14	.26	.30	.49	.83	1.11
FLASHING LIGHT DLM	REF	.00	.00	.75	1.36	1.23	2.45	4.11	5.19
RATE GYRO DLM	REF	.00	.00	24.99	67.60	63.31	123.02	160.82	257.44
CABLE REUSABLE DLM	REF	.00	.00	22.37	67.19	65.87	108.24	177.11	250.99
SENSORS DLM	REF	.00	.00	.90	1.62	2.94	5.06	7.21	10.26
ACTUATOR DLM	REF	.00	.00	.00	55.57	102.36	140.80	229.92	329.06
POWER SUPPLY DLM	REF	.00	.00	.00	267.86	301.39	422.71	645.85	1005.84
NOSE FRUSTRUM DLM	REF	.00	.00	154.24	242.87	324.81	499.40	897.13	1221.07
FORWARD SKIRT	REF	.00	.00	.00	461.13	489.39	770.47	1075.68	1691.50
FORWARD TUNNEL DLM	REF	.00	.00	3.15	8.39	9.42	17.19	24.90	36.06
AFT TUNNEL DLM	REF	.20	.00	2.88	5.22	5.99	10.43	16.03	22.73
REUSABLE STRUTS BAC DLM	REF	.00	.00	6.77	20.34	19.90	36.58	54.90	76.96
AFT SKIRT BAC REF	REF	.00	.00	.00	674.93	636.44	991.49	1465.49	2332.27
ET ATTACH RING BAC DLM	REF	.00	.00	10.38	18.69	23.59	36.88	58.93	80.71
SATELLITE FLOATS BAC DLM	REF	.00	.00	8.23	20.48	21.93	40.82	66.10	101.17
TOTAL		.20	.00	245.97	2581.80	2901.23	4370.55	6486.62	9811.86

ANNUAL SUMMARY		FY1985	FY1986	FY1987	FY1988	FY1989	FY1990	FY1991	FY1992
INTEGRATED ELECTRONIC AS	REF	3022.88	3202.37	3312.99	3704.97	3449.65	3887.86	1695.80	2034.51
ALTITUDE SWITCH DLM	REF	30.57	32.51	38.19	39.19	36.65	40.20	38.67	4.77
FRUSTRUM LOCATION AID DL	REF	48.48	50.47	53.18	60.93	56.71	61.47	63.69	6.31
RF BEACON DLM	REF	18.52	19.29	20.74	23.68	21.28	23.88	24.38	2.80
RF BEACON ANTENNA DLM	REF	1.11	1.29	1.28	1.52	1.42	1.53	1.53	.31
FLASHING LIGHT DLM	REF	5.61	5.88	5.95	7.38	6.83	7.23	7.35	.99
RATE GYRO DLM	REF	267.27	280.04	283.15	340.20	324.14	350.94	344.07	37.02
CABLE REUSABLE DLM	REF	255.13	277.60	274.75	340.31	294.29	336.77	336.60	47.56
SENSORS DLM	REF	12.86	13.53	14.30	15.10	15.91	16.00	17.23	5.25
ACTUATOR DLM	REF	445.20	508.49	529.04	587.01	585.28	633.79	642.42	381.40
POWER SUPPLY DLM	REF	1164.82	1298.53	1344.38	1520.71	1385.06	1566.61	1646.09	806.11
NOSE FRUSTRUM DLM	REF	1240.46	1321.02	1390.04	1591.67	1546.02	1633.14	1631.51	197.52
FORWARD SKIRT	REF	2041.53	2237.15	2289.04	2645.93	2427.82	2752.34	2761.30	1420.15
FORWARD TUNNEL DLM	REF	37.34	39.70	39.26	49.28	43.71	48.03	49.00	4.76
AFT TUNNEL DLM	REF	23.62	24.67	25.98	31.37	28.28	31.63	31.06	3.69
REUSABLE STRUTS BAC DLM	REF	78.27	85.11	87.81	106.74	93.81	104.93	106.04	12.23
AFT SKIRT BAC REF	REF	2790.47	3083.32	3085.71	3628.12	3363.58	3619.32	3752.67	1976.58
ET ATTACH RING BAC DLM	REF	85.81	89.53	94.11	109.63	96.79	112.76	115.10	8.76
SATELLITE FLOATS BAC DLM	REF	104.20	118.87	121.76	142.54	137.70	161.05	156.99	16.80
TOTAL		11674.17	12689.36	12946.66	14945.28	13913.30	15389.40	15311.43	7817.53

Figure 53. WBS summary table 5 - SRB refurbished hardware.

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                 WBS SUMMARY TABLE 5
MIPS>          SR3 REFURBISHED HARDWARE
 COSTS FOR FY1977 THROUGH FY1992
 ---------------------------------------------------
 INTEGRATED ELECTRONIC AS REF             33754.09
 ALTITUDE SWITCH DLM      REF               335.83
 FRUSTRUM LOCATION AID DL REF               533.67
 RF BEACON DLM            REF               203.20
 RF BEACON ANTENNA DLM    REF                13.13
 FLASHING LIGHT DLM       REF                62.31
 RATE GYRO DLM            REF              2332.03
 CABLE REUSABLE DLM       REF              2334.78
 SENSORS DLM              REF               133.17
 ACTUATOR DLM             REF              5170.41
 POWER SUPPLY DLM         REF             12375.95
 NOSE FRUSTRUM DLM        REF             13330.98
 FORWARD SKIRT            REF             23052.83
 FORWARD TUNNEL DLM       REF               410.17
 AFT TUNNEL DLM           REF               263.58
 REUSABLE STRUTS BAC DLM  REF               833.40
 AFT SKIRT   BAC REF      REF             31341.33
 ET ATTACH RING  BAC DLM  REF               541.62
 SATELLITE FLOATS BAC DLM REF              1218.36
 ---------------------------------------------------
 TOTAL COST FOR FY1977 THROUGH FY1992
 FOR WBS SUMMARY TABLE 5                 130234.13
```

Figure 53. (Concluded).

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APPENDIX A

MCONV2 MISSION MODEL CONVERSION

MCONV2 is a FORTRAN program which converts launches per quarter data to launch interval data. ETR and WTR launches are scheduled independently. Two passes are made through the program. The first pass is made to process launches per quarter ETR data and the second pass is made to process launches per quarter WTR data. Launches per quarter data is read from a file and stored via a DATA statement into an array, LPQ, which allows for 56 quarters with the first storage word being for FY79/1.

The program provides to the user the capability to specify specific launch dates by calendar year, day, and month for both ETR and WTR launch sites. Specific launch dates are read from a file, and calculations are made to store the dates in days elapsed since the start of FY79/1 format.

The scheduling logic for quarters without fixed dates first divides the quarter by twice the number of launches to get DT. Then one DT into the quarter is the time for the first launch of the quarter. The time increment to each succeeding launch in the quarter is 2*DT. The last launch is one DT before the end of the quarter.

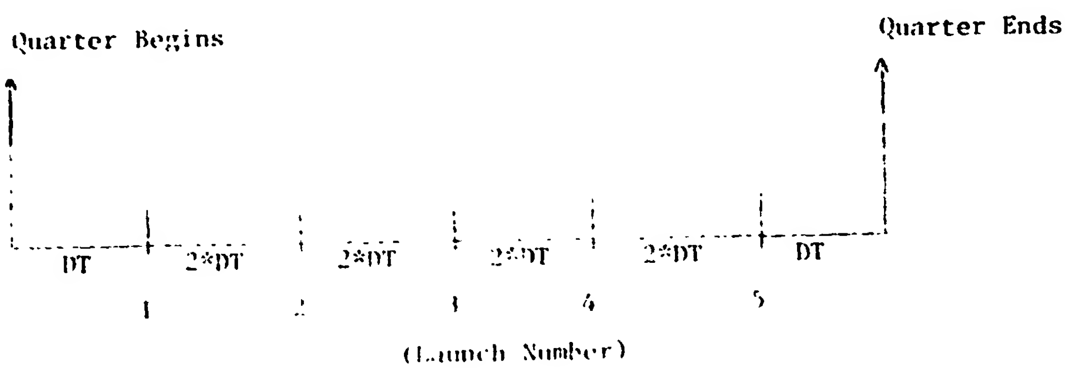


Figure A-1.

If the quarter has both fixed dates and dates to be computed by the program, the scheduling logic first divides the quarter by twice the number of non-fixed launches to get DT. The logic is the same for computing intervals as if there were no fixed dates. Then each interval between fixed dates is viewed as if it is a quarter and is divided by twice the number of launches that fall within that interval to get DT_1.

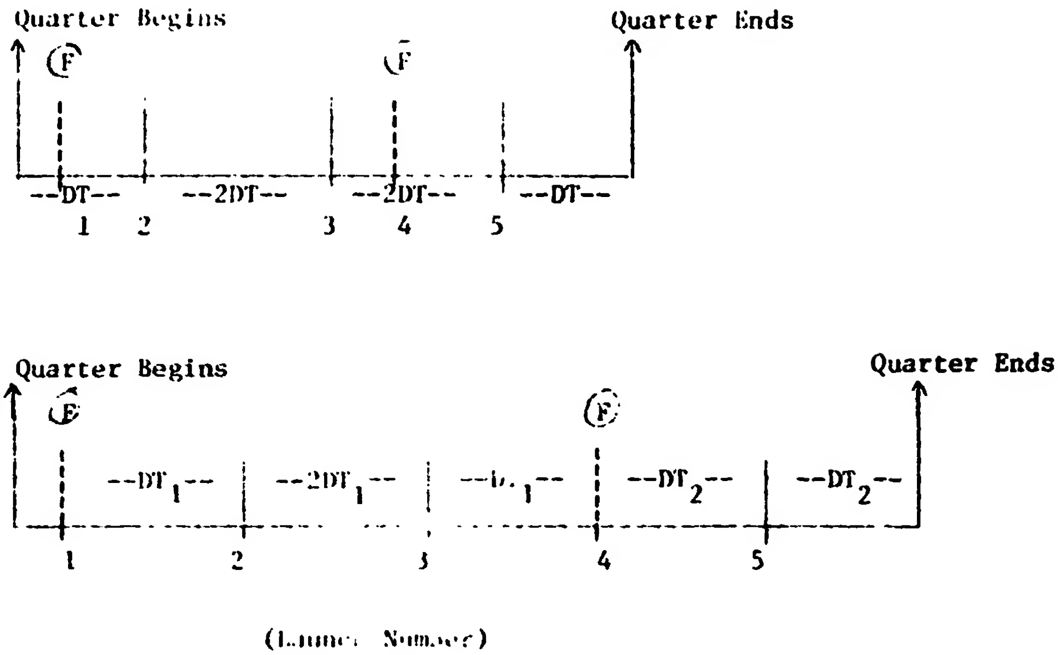


Figure A-2.

Output includes both punched cards and printed tables. Launch interval data is output via punched cards in the format required for GPSS functions. A table is printed which includes:

- ETR and WTR identifier.
- Cumulative total launch number (overall).
- Cumulative total launch number (for the particular site).
- Calendar month, day, year of launch.
- Fiscal year/quarter of launch.
- Days elapsed since last launch at this site.

A flowchart of MCONV2 is shown in Figure A-3.

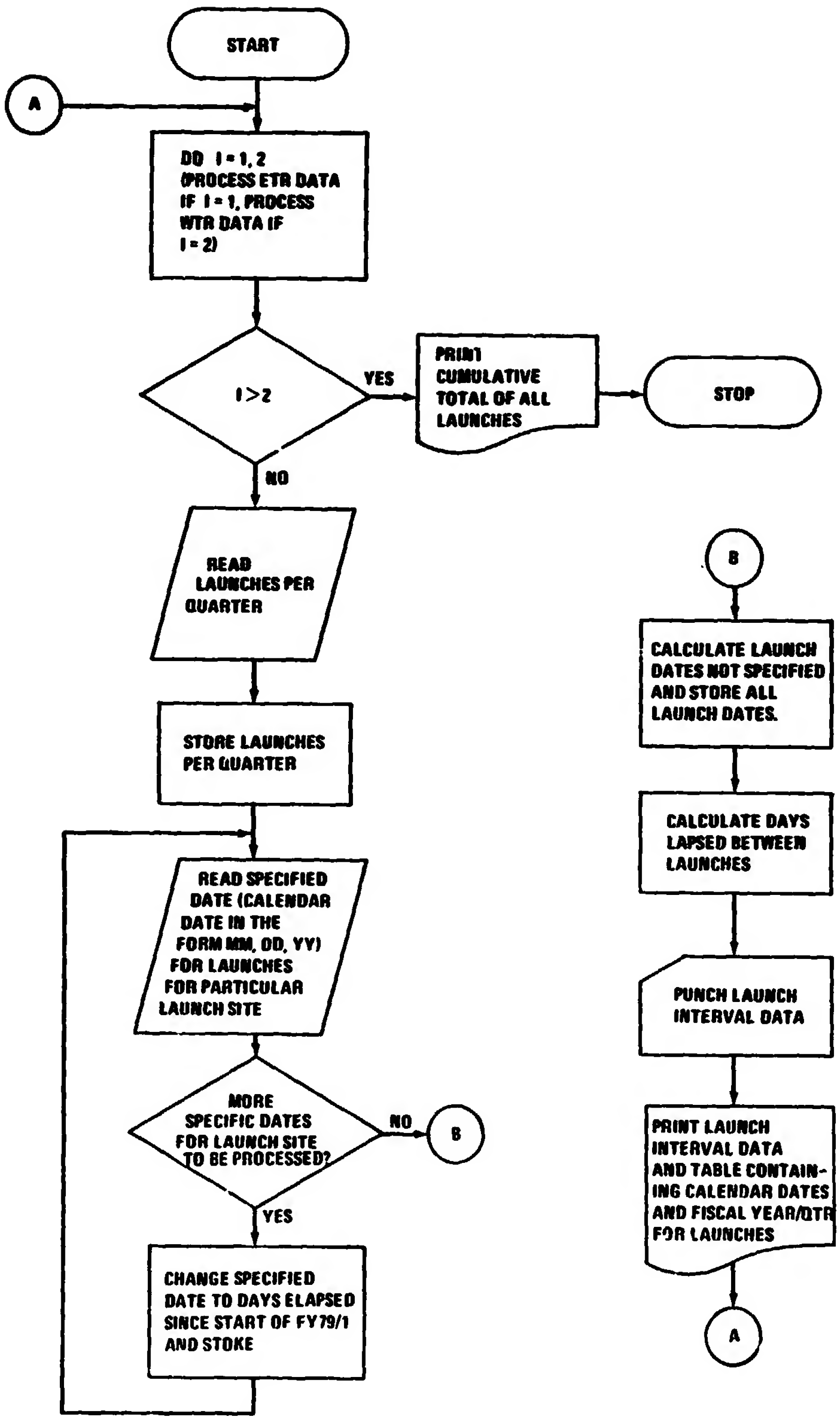

START
A
DO I = 1, 2
(PROCESS ETR DATA
IF I = 1, PROCESS
WTR DATA IF
I = 2)
I > 2
YES
PRINT
CUMULATIVE
TOTAL OF ALL
LAUNCHES
STOP
NO
READ
LAUNCHES PER
QUARTER
STORE LAUNCHES
PER QUARTER
READ SPECIFIED
DATE (CALENDAR
DATE IN THE
FORM MM, DD, YY)
FOR LAUNCHES
FOR PARTICULAR
LAUNCH SITE
MORE
SPECIFIC DATES
FOR LAUNCH SITE
TO BE PROCESSED?
NO
B
YES
CHANGE SPECIFIED
DATE TO DAYS ELAPSED
SINCE START OF FY79/1
AND STORE
B
CALCULATE LAUNCH
DATES NOT SPECIFIED
AND STORE ALL
LAUNCH DATES.
CALCULATE DAYS
LAPSED BETWEEN
LAUNCHES
PUNCH LAUNCH
INTERVAL DATA
PRINT LAUNCH
INTERVAL DATA
AND TABLE CONTAIN-
ING CALENDAR DATES
AND FISCAL YEAR/QTR
FOR LAUNCHES
A

Figure A-3.

APPENDIX B

BOOSTER SIMULATION (BOSIM) PROGRAM

INTRODUCTION

This summary presents a narrative description of the current Solid Rocket Booster (SRB) Simulation Models, BOSIM Versions 3 and 4. This summary is intended for the nonprogrammer and does not cover the input and output in the detail of the user's guides, References 7 and 9. The primary purpose of this summary is to describe some important features of the SRB's planned operation through cycles of use and refurbishment and to describe the manner in which these features are treated in the computer operated models. The two currently used versions of BOSIM both model the same system and are different primarily because Version 4 treats only 1 subsystem at a time while Version 3 simultaneously treats 19. Version 4 is easier to use and produces results equivalent to the more versatile Version 3 under the groundrules used for most studies. Reference 3 presents brief descriptions of many of the groundrules and definitions currently applicable. This summary expands and adds to the descriptions in Reference 7 with emphasis on the specifics of implementing groundrules in the models.

SCOPE OF THE MODELS

The BOSIM models are General Purpose Systems Simulation (GPSS) models which simulate the operational cycles of the major subsystems of the Space Shuttle's Solid Rocket Booster (SRB). The reusable subsystems of the SRB are tracked through cycles of assembly, use, disassembly, and refurbishment.

Figure 8 illustrates the operational cycle of a typical subsystem, the nose frustum, as it is simulated in the model. Each copy of a subsystem is tracked from the time it is received from the manufacturer until it is lost or worn out. The time period of the simulations is usually from the beginning of fiscal year 1979 through fiscal year 1990.

A list of subsystems currently modeled is provided in Figure B-1. When the differences between subsystems are not considered significant for the purposes of current applications, two or more subsystems are combined under one name and set of characteristics. The drogue and main parachutes are currently combined under the name "parachutes" because their loss risks, refurbishment times, maximum reuses, and so forth are the same. In the past, the aft Instruments and Electronics Assembly (IEA) and the forward IEA were similarly combined. They are

SUBSYSTEM	REFURBISHMENT (Days)*	TRANSPORTATION FROM REFURB (Days)	ASSEMBLY (Days)*	RETRIEVAL (Days)	DISASSEMBLY (Days)*	TRANSPORTATION TO REFURB (Days)	AVERAGE LOSS PROBABILITY (PERCENT)	MAXIMUM NUMBER OF USES
SRM								
Aft Cylinder	83	16	36.5	4	29.2	9	3.6	20
Forward Cylinder	83	16	36.5	4	29.2	9	3.4	20
Middle Segments	83	16	36.5	4	29.2	9	3.2	20
Aft Stiff Tees	4	0	29.2	4	12.8	0	3.3	40
Nozzle	83	16	36.5	4	29.2	9	3.2	20
Compliance Ring	83	16	36.5	4	29.2	9	4.0	20
Igniter	83	16	36.5	4	29.2	9	3.2	20
E&I (Operational)								
Forward IEA	10.5	0	29.2	4	10.9	0	2.9	20
Aft IEA	7	0	29.2	4	10.9	0	2.9	20
TVC								
Actuator	29	0	29.2	4	16.4	0	3.7	20
Power Supply	29	0	29.2	4	16.4	0	2.9	20
STRUCTURES								
Nose Frustrum	40	0	29.2	4	7.3	0	2.9	40
Forward Skirt	10.5	0	29.2	4	18.2	0	2.9	40
Systems Tunnel	4	0	29.2	4	12.8	0	2.9	40
ET Attach Ring	4	0	29.2	4	12.8	0	2.9	40
ET Attach Struts	4	0	29.2	4	12.8	0	2.9	40
Aft Skirt	29	0	29.2	4	16.4	0	2.9	40
RECOVERY								
Parachutes	22.5	0	29.2	4	0	0	8.0	10
Recovery Aids	22.5	0	29.2	4	0	0	2.9	20

Values are for first unit at ETR. Learning curves are applied.

Figure B-1. Typical input values.

now treated separately because of differences established in their refurbishment durations. Expendable subsystems are not included in the models because the quantities to be bought, worn out, and so forth can be determined by simpler methods.

Shipsets, consisting of all the essentially identical units which go into one SRB, are the smallest entities considered. A shipset may consist of one unit such as the nozzle, or four stiffener tees, depending on how many are included in one complete SRB. One Shuttle launch requires two SRB's or two shipsets of each subsystem considered. Not included in the model is consideration of reuse of complete or partial shipsets after they have been classified as lost due to accidental damage. For Version 3, the complexities involved in utilizing partial shipsets would probably require a larger model than could be accommodated with the computer resources now available.

The simulations include new hardware when it is delivered. The events involved in getting new subsystem copies built and shipped to a storage facility where they await assembly into an SRB are not included in the BOSIM models.

The models perform what is basically a large bookkeeping task. Each copy of a subsystem is tracked from one activity to another from the time it is delivered until it is lost or worn out or the end of the time period being studied is reached. If this were to be done manually, the procedure would be something like the following:

Step 1 — Set the simulated time or simulation clock to the time of the first event.

Step 2 — Make the status changes required at that time. For example, a subsystem copy is taken from storage and started through the SRB assembly procedure.

Step 3 — Calculate the time when each copy will finish the activity it just started and schedule the next future status change event for each copy.

Step 4 — After all the current status changes are completed, scan the list of future events and pick the nearest future time when the status of some part of the system is due to change.

Step 5 — Move the simulation clock forward to the next event time. Return to Step 2 and continue until the period of the simulation (currently 12 years) is completed.

The status of each subsystem copy is kept in the form of entries on tables. One table specifies where the subsystem copy is at the current simulated time. Other tables carry specifics about each copy, such as when it entered the system, how many uses it has accrued,

its serial number, its scheduled departure time from its present status, and so forth. Other tables keep track of the status of the system, such as how many nozzles are currently being refurbished, assembled, and so forth.

The point of the preceding description is that each item is tracked individually. In the simulation models, a specific identifiable set of equipment makes up each SRB at launch.

Unfortunately, reality is not perfectly predictable, so the models must have analogous features of unpredictability. The random occurrence of accidents is modeled by inputting loss probability curves which are used with random number generators to select specific subsystem copies to be lost. During one simulation run, the random number generators may produce unusually favorable or unfavorable loss patterns, so 25 runs are normally made and the results are averaged.

Crawford method learning curves are applied to operations such as assembly, disassembly, and refurbishment to account for the decreases in the duration of these activities which result from improving methods and worker skills with experience. The details of learning curve applications and other groundrules are covered in the following sections.

Both design, development, test, and engineering (DDT&E) and operational phases of the Shuttle era are covered by the models.

MISSION SEQUENCE

In this section, the sequence of events which occurs during the simulation of one mission is described. In subsequent sections, particular characteristics relating one mission to others are explained.

The simulation a mission begins at the time prior to launch when the first of the SRB subsystems is required to be physically committed to the mission. This time, called the assembly start time, marks the latest time prior to launch that one subsystem shipset could be substituted for another without perturbing the normal prelaunch events. At the assembly start time, the choice of a refurbed shipset is made, or a new shipset is assumed to be delivered if no refurbished shipset is available. In the current models, no waiting for equipment past the assembly start time is permitted since on-time launches are required.

In Version 3, the model progresses through an assembly sequence. This means that as time advances the other subsystem shipsets are committed to the mission in the same manner as the first subsystem. For each subsystem, the choice of which shipset will be used is made as late as possible preceding the scheduled launch time. (In reality, it will be possible and desirable to anticipate the shipset choices for a mission. In the models, there is no need to know the choices earlier than the time the commitments must be made.)

In Version 4, only one subsystem is considered, so the assembly time begins at the latest time that the subsystem shipset can be committed and ends at launch with no events (concerning the same mission) in between. A learning curve factor which reduces the length of the assembly time as experiences increase is used.

Launch occurs and the two SRB's splash down separately. An input sinking probability is used with a random number generator to select those SRB's which sink. A sinking terminates consideration of one shipset of each subsystem and contributes to the counts of lost equipment output by the model. A constant 0.2 percent is currently used for the sinking probability at both splashdown areas.

For those SRB's which do not sink, the next interval simulated includes the flight phase, splashdown, retrieval, return to the launch site, and unloading of the SRB's from the retrieval ship. A single time is input for this period and no learning curve factor is applied.

The disassembly sequence of events is treated in a manner similar to the assembly sequence. The times required to separate each shipset from the other subsystem shipsets are inputs. As the simulated time advances, each subsystem shipset is released in turn until all are separated. A learning curve factor which reduces the disassembly duration as the count of disassemblies increases is used.

In Version 4, only one subsystem is considered, so only one interval, the time between disassembly start and release of the subject subsystem, is used in the simulation.

From the time of its release, each subsystem shipset is tracked separately. A probability of loss is input for each subsystem for application at this point in the event sequence. It is assumed that if water impact damage makes a shipset unfit for the normal refurbishment procedure, that fact will be discovered during disassembly. A random number generator is used with the subsystem's loss probability to select the shipsets to be lost. Those shipsets which are selected leave the system permanently and contribute to the counts of lost equipment. The loss probability is varied by application of a learning curve.

The number of uses accrued on the subsystem shipset is compared with the maximum uses permitted, which is a constant for each subsystem type, and those that are worn out are counted and permanently removed from the system instead of going to refurbishment.

Those shipsets qualifying for refurb, by virtue of passing the loss and wearout tests, are immediately sent to their respective refurb sites. Only the time required for transportation is considered in the model. No equipment waits to fill a barge or any other vehicle before the shipping interval is started. Every qualified shipset goes to refurb, regardless of whether there is a predicted need to use it again to finish the launch schedule. The transportation to refurb intervals are input and do not change during the simulated time period.

In the current models, unlimited refurbishment facility capacities have been assumed. In other words, all shipsets begin their refurb activities upon arrival at the refurb site. None are required to wait due to the facility being busy processing previous arrivals. The duration of each subsystem's refurb is an input, but the time is reduced with experience.

At completion of the refurb activity, the shipset is immediately shipped back to the launch site where it is to be used next. (If the refurb is done at the launch site, the input value for shipping time is small or zero.) The shipset is then available for reuse on a subsequent mission. The method of choosing shipsets from the available pool is discussed in the AVAILABLE POOL section.

SUBSYSTEM ASSIGNMENT

SRB subsystems are either "dedicated" or "shared." If a subsystem is classified as dedicated, the shipsets used at the Eastern Test Range (ETR) are never used at the Western Test Range (WTR) and vice versa. If a subsystem is classified as shared, a given shipset may be used in SRB's launched at both ETR and WTR. For example, nozzle number 1 (classified as shared) might be used for ETR missions 1 and 7, then for WTR mission 1, then for ETR mission 30, and so forth. Because forward skirts are not shared, one used for an ETR mission will never be used in an SRB launched at WTR.

Sharing usually has the effect of reducing the number of shipsets required to meet a launch schedule, because equipment which would be idle at one site can be used at the other site. Currently, sharing is limited to the Solid Rocket Motor (SRM) subsystems which are to be refurbished in Utah. Sharing is a logical choice when a single refurb facility supports both launch sites. When separate facilities are used, sharing becomes progressively less attractive as transportation times and costs increase.

LEARNING CURVES APPLIED TO DURATIONS

Crawford method learning curves are applied to assembly, disassembly, and refurbishment durations in the models. The learning curve factor (LCF) is a fractional multiplier which produces an exponential decay in the event duration as the number of repetitions increase. Figure B-2 shows the 93-percent slope learning curve which is applied to ETR assembly, disassembly, and refurbishment durations The equation for the learning curve factor is

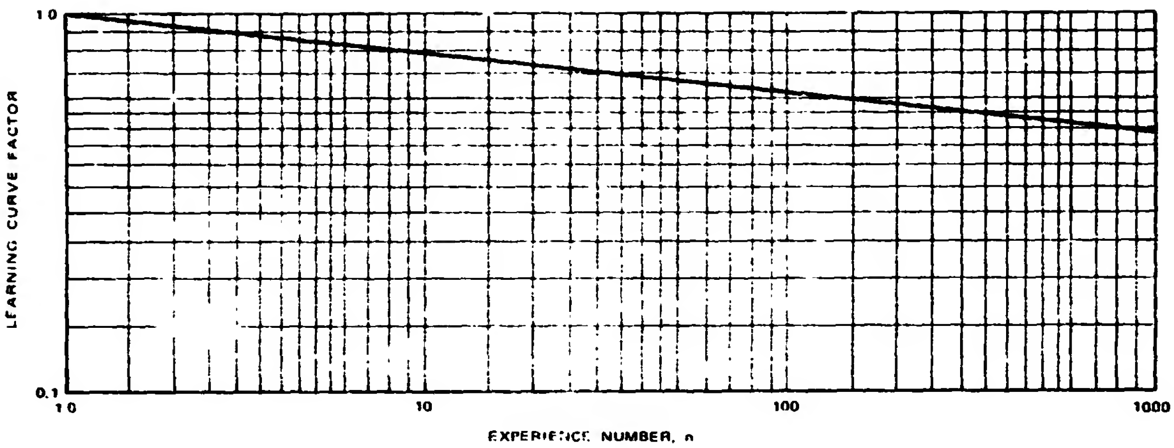


Figure B-2. Crawford learning curve with 93-percent slope.

$$LCF_n = (n)^{\frac{\log S}{\log 2}}$$

where

n is the flight number

and

S is the slope expressed as a fraction, that is, for a 93-percent learning curve slope, S = 0.93.

The event duration is the first unit duration multiplied by the learning curve factor

$$\text{Duration} = TFU \times LCF_n$$

where

TFU is the duration of the activity the first time it is performed

and

LCF_n is the learning curve factor for the nth flight.

The learning curve slope currently groundruled for ETR operations is 95 percent. The slope was chosen to satisfy a requirement that the last refurbishment duration be at least 50 percent of the first unit duration. For lack of better data, the same slope has also been used for assembly and disassembly operations.

It has been assumed that the WTR operations will benefit from the learning at ETR. Consequently, the first refurb at WTR should have approximately the same duration as the then current refurbs at ETR. Also, because fewer missions are launched at WTR than ETR, WTR's learning will always trail ETR's. The degree of learning transfer is debatable, but for these models a high level of learning transfer has been assumed. In practical terms, this means that WTR follows a learning curve which stays very close to ETR's as time progresses. The learning curve slope chosen for WTR is 97 percent. The first unit durations for WTR are two-thirds of the ETR first unit durations because of the assumed learning transfer by the time of the first WTR mission in FY 1983. Figure B-3 shows the learning curve factors for ETR and WTR assembly activities versus time.

Those operations done in Utah, refurbishing the SRB subsystems, are assumed to operate on 93-percent slope learning curve also.

While the same slope is currently input for assembly, disassembly, and refurbishment, the curves are applied differently. The SRB's are assembled in pairs and the number of learning experiences is equal to the number of pairs which have passed through the assembly facility. For the 100th mission, the 100th value on the learning curve is applied to the TFU assembly time.

Learning is applied to the disassembly activity as follows. If both SRB's from one mission are recovered, each has the same learning curve factor (LCF). The number of experiences is the sum of flights where at least one of the SRB's was recovered. In practice, this means that the same learning occurs with each flight whether one or two SRB's are disassembled. For the 100th flight, some earlier value on the learning curve (perhaps the 98th) will be applied since some missions will result in both SRB's sinking.

The individual SRB subsystem shipsets go to refurbishment, if qualified as described earlier, and each shipset refurbished counts as an experience. If no hardware were lost or worn out, each second shipset from the 100th flight would use the 200th value on the learning curve. Each first shipset would use the 199th value.

The effect of the preceding applications of the learning curves is that the refurbishment durations decrease faster percentagewise than the assembly durations which also decrease faster than the disassembly durations. This is true as long as the same slopes are input for these activities.

The slopes (and so forth) currently used are somewhat arbitrary and are subject to change as better definition of the SRB system is obtained.

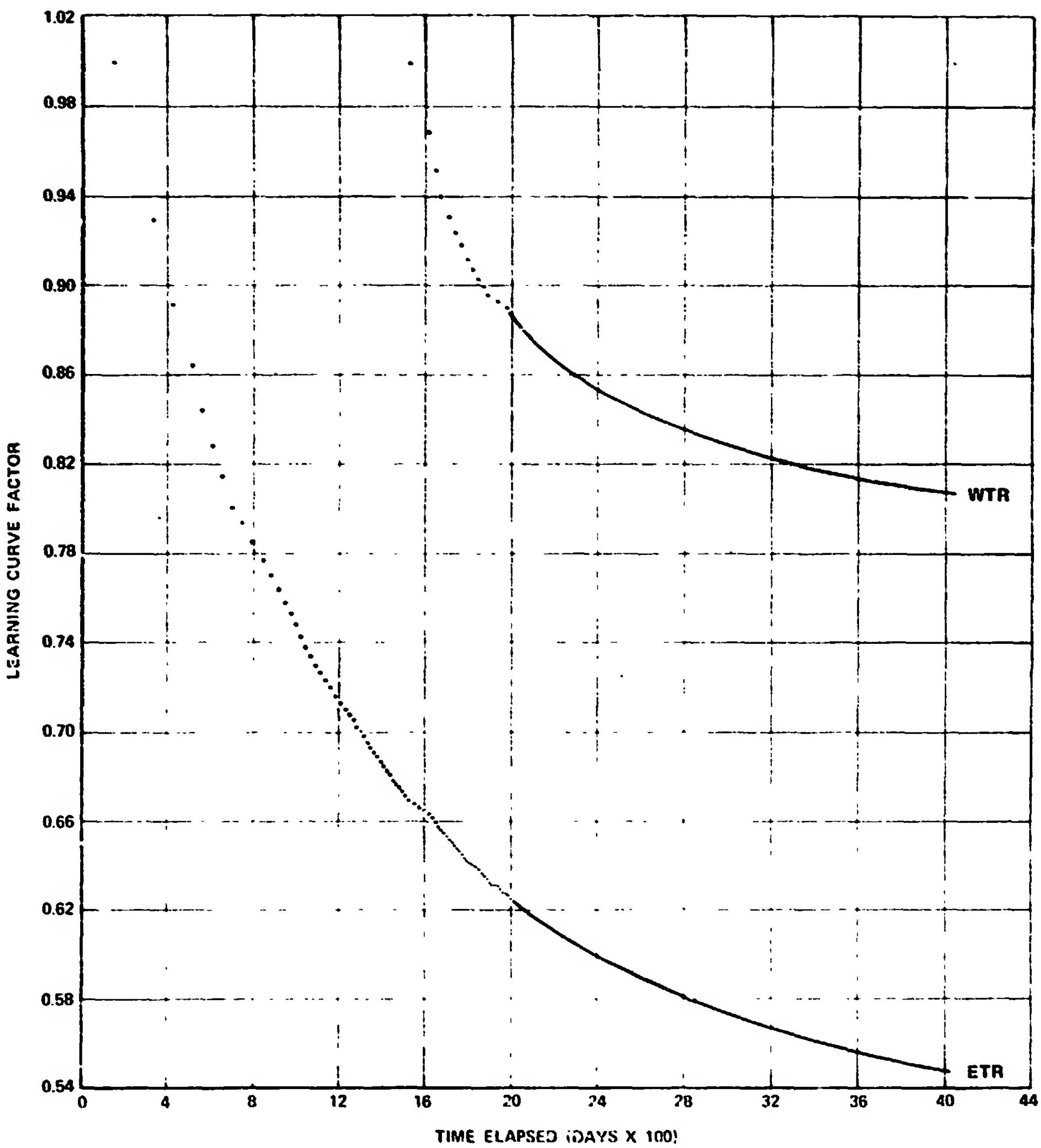


Figure B-3. Assembly learning curve factors.

LEARNING CURVES APPLIED TO LOSS PROBABILITIES

As noted earlier, a separate loss probability is applied to each subsystem of each disassembled SRB at the time each subsystem is separated from the remainder of the SRB subsystems. A current groundrule specifies that there is a 50-percent probability of loss or risk for the first shipsets flown. Other inputs specify the 12-year average loss probability for each subsystem as shown in Figure B-1. If a learning curve is used, its slope must be chosen to satisfy the two constraints for a given number of experiences or exposures to loss in this case. Finding the number of exposures is a "chicken and egg" problem, because the number depends on how many new shipsets are used and the number of new shipsets depends on how many are lost. For purposes of determining a slope, the number of exposures is assumed to equal the number of Shuttle flights. The equations which follow are used to obtain the loss probability learning curve slopes by iterating on values of slope until the resulting average is the desired value.

$$A = \frac{(n + 0.5)^{1-B} + 1 - B - (1.5)^{1 - B}}{n(1 - B)} \times \frac{F\%}{100\%}$$

$$B = \frac{-\log\ (\text{slope})}{\log\ 2}$$

where

A is the desired average risk of loss,

n is the number of exposures to loss,

F is the percent loss probability of the first shipset,

and

slope is the calculated learning curve slope fraction.

Once the slopes are available, the loss probability for each disassembled shipset may be calculated as the product of the first unit value, 50 percent, and the learning curve factor.

$$\text{Risk} = F\% \times \text{LCF}$$

Shipsets are picked for loss in simulations by comparing random numbers to the current loss probability. For example, if the loss probability

were 10 percent, a loss would occur when the random number was within a prepicked 10 percent of the possible random number values.

AV...ABLE POOLS

After a shipset is refurbished, it is considered to be a member of a group of shipsets available for reuse or, more concisely, it is in an available pool. In reality, the next flight for a given subsystem shipset will probably be decided as soon as its time to complete refurbishment can be predicted with certainty. Consequently, most (if not all) of the refurbished hardware will have at least a tentative next flight assignment when it comes out of refurb, and there will be no problem in determining where to ship it. Modeling the predictive aspects of reality is very difficult and, fortunately, unnecessary in this situation. An alternative concept, the available pool, produces the same results and can readily by modeled. The only assumption required is that the choice of hardware for a mission is made as late as possible, that is, when it must be physically committed to the assembly sequence. The choice from the shipsets then available is based on the number of uses accrued on each. Currently, the newest hardware, in terms of number of uses, is chosen first.

The areas of use philosophy, including which of the available shipsets should be chosen, is currently under study. It is relatively easy to modify the models to use alternative logics such as giving priority to particular serial number shipsets, using a first-in-first-out logic, switching from oldest first to newest first at some preset time or condition, and so forth.

MANUFACTURING RATE

The models are formulated so that no shipset quantities must be guessed prior to running the simulations. The model determines how much hardware is needed by adding a shipset whenever one is required to avoid a missed or delayed launch. The resulting delivery schedule shows the latest times when hardware can be received without missing a planned launch.

A second option allows delivery schedules to be specified. For example, 74 SRB segment sets might be delivered beginning in 1979 at the rate of one per month. If the input delivery schedule does not provide sufficient shipsets, then additions are automatically made as required and reflected in the output. Early delivery of hardware can have the effect of reducing the total quantity required because the uses are better distributed over the shipsets. This behavior is currently under study in conjunction with the logic for choosing a shipset from the available pool.

DDT&E HARDWARE REUSE

Design, development, test, and engineering (DDT&E) hardware is groundruled not to be reflown before the seventh Shuttle flight. This constraint is included in the models by preventing DDT&E shipsets from entering their respective available pools after refurbishment until choices for the sixth flight are completed. Consequently, new shipsets are used to assemble the 12 SRB's used on the 6 DDT&E flights.

MODEL APPLICATIONS

The models were developed to determine quantities of hardware required to support a launch schedule using realistic constraints and avoiding assumptions about how many uses could be obtained from individual subsystem shipsets. The models have been coded in General Purpose Systems Simulation (GPSS) form instead of Fortran or some other language because of the significantly more flexible nature of GPSS models and the shorter coding times required. Simulation models incorporate groundrules which may be considered analogous to the laws of physics in a trajectory analysis or other analytic program. A trajectory program can be set up as a black box suitable for use by nonprogrammers since the groundrules, the laws of physics, do not change. A simulation model frequently does not have a constant set of groundrules over a long period. Simulation models consequently have limited independent usability by nonprogrammers. The applications discussed in the following paragraphs are not simply available by setting option flags or setting up the appropriate set of input data cards. In many cases, the application is or requires a variation in the groundrules or may be affected by other groundrule changes so that working with the coding cannot be avoided.

One significant groundrule currently under study involves the choice of hardware from the available pools as mentioned earlier. Each modification to prepare a deck for that type of study is relatively minor and can usually be completed in less than 2 days.

Some studies can be accomplished without coding changes, particularly with the single subsystem simulation, Version 4, which has so. easily understood inputs. Changes to refurbishment, transportation, assembly, disassembly, and retrieval times; learning curve slopes; loss rates; and maximum uses per shipset can be easily made by any user. With a little instruction, launch schedules and some other quantities can also be modified. For further information see References 9 and 7, a Programmer's Manual for Version 3 and the User's Guide for Version 4.

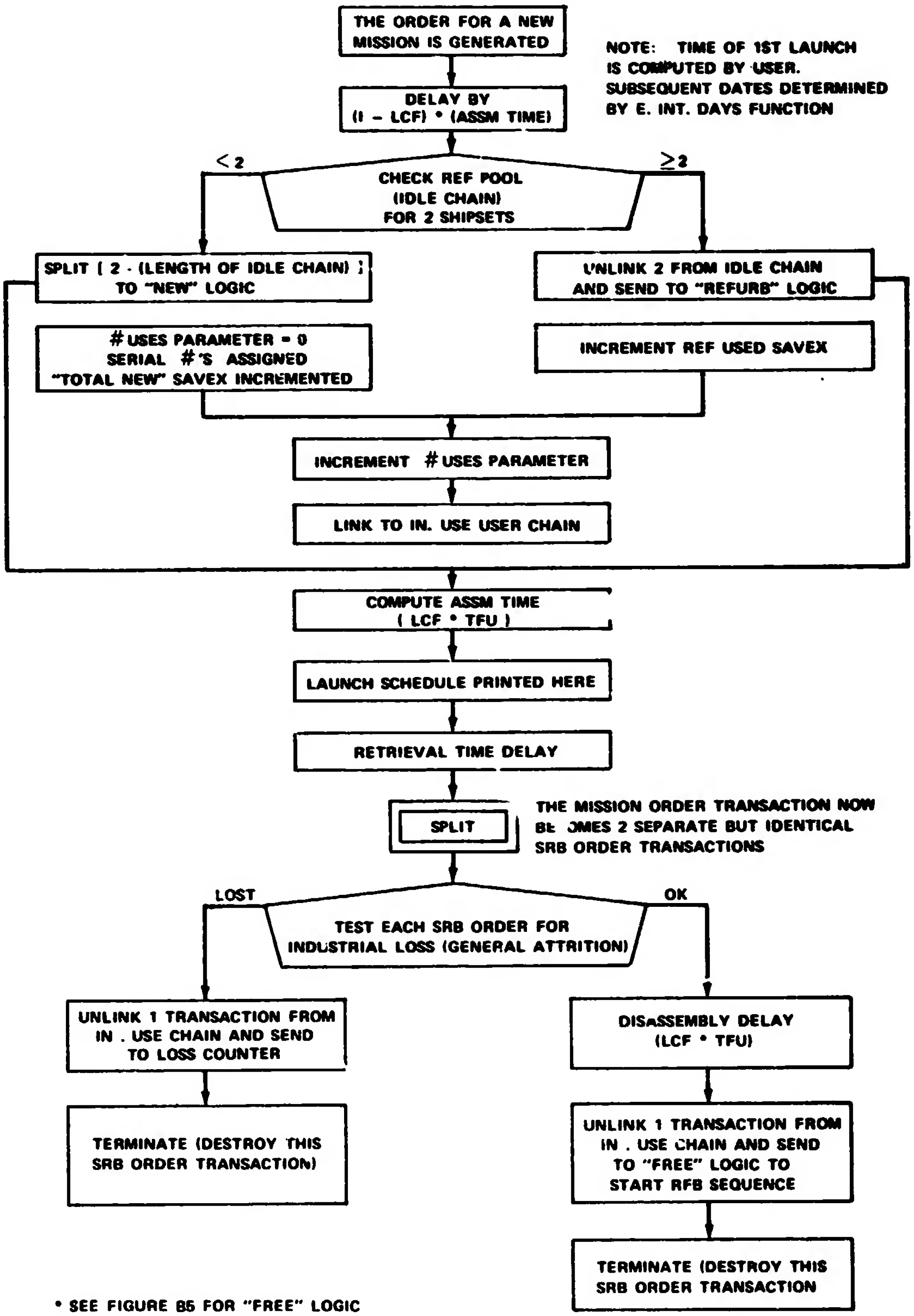


Figure B-4. BOSIM flowchart.

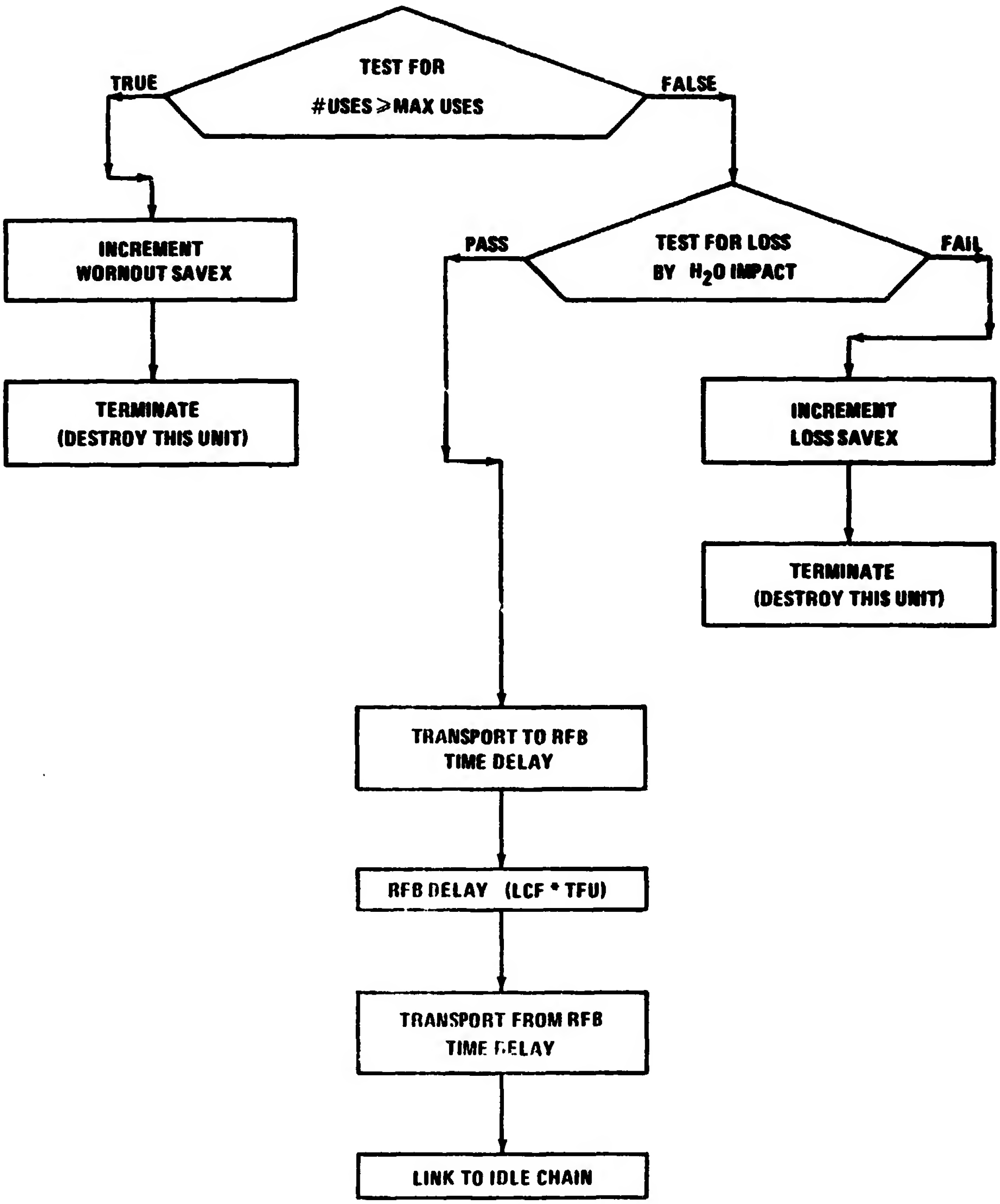


Figure B-5. "I RI'''" logic (RFB sequence).

APPENDIX C

GRAH COMPUTER PROGRAM

INTRODUCTION

The GRAH package consists of two separate programs: SMLMAC and BIGMAC. Both are independent programs and each can be executed separately. SMLMAC creates new data files or updates existing data file in the format required by BIGMAC, which processes these files. BIGMAC processes data files made available by SMLMAC in Graphic Analysis of Hardware Requirements.

The GRAH programs were developed on a PDP 11/46 installation with a TEKTRONIX 4010 Graphic Computer Display Capability. These programs are designed to be interactive with a minimum of effort provided by the user. Detail instructions, which query the user for responses, are displayed on the CRT terminal. Either program can directly access individual records from the data files. This option promotes user convenience as well as saving both man and machine time. The individual capabilities of each program are described separately.

SMLMAC - PROGRAM DESCRIPTION

SMLMAC is an important part of Graphic Analysis of Hardware Requirements Software Package. SMLMAC can create new files or update existing data files whose records are unformatted and can be accessed directly. The length of each record is predetermined to be 52 words so that it would be in accordance with the length required by BIGMAC. The files made available by SMLMAC may be used by other programs which require similar data. SMLMAC is capable of receiving input data from punched cards or from Tektronix Interactive Terminals.

Detail instructions along with data input formats are displayed on the terminal. These instructions aid the user throughout the execution of the program. The punched card input to the SMLMAC program should have the following format:

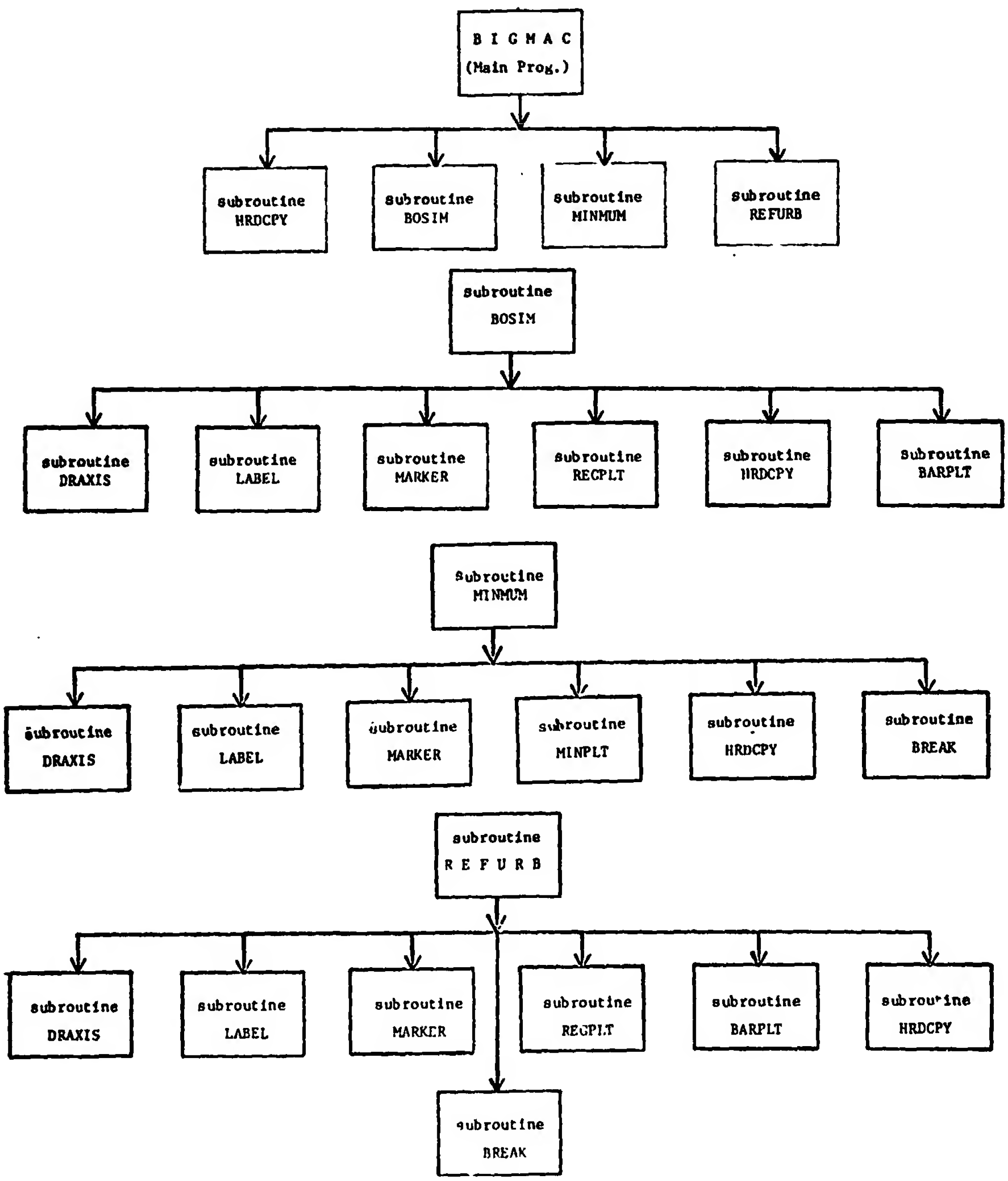
Card Column	Format	Description
1	A1	Not used at this time. Leave blank.
2-17	16A1	Name of the subsystem.
18-62	15I3	Number of hardware units required. A 3 digit integer for each of 15 years.
63-64	I2	Number of units per shipset.
69-70	I2	Record number to be updated (this field is required only when updating an already existing file. This field is ignored if a new file is being created.)

BIGMAC - PROGRAM DESCRIPTION

BIGMAC is the main program of Graphic Analysis of Hardware Requirements Software Package. This program, which is independent of SMLMAC, uses data files made available by SMLMAC in analyzing hardware requirements. This program has the ability to make temporary changes to individual records before they are processed. BIGMAC, upon request, will provide the user with hard copies of all analyzed output data that is displayed on Tektronix Graphic Computer terminal, or leave the option of copying to the user by only reminding with a slightly longer than ordinary bell tone. BIGMAC, also at user's option, can provide requested output for all subsystems in the data file sequentially or allowing the user to process individual records. In addition, the program provides a complete listing of the assigned data file before processing any of the records.

BIGMAC provides separate or any combination of outputs for new, refurbished, and minimum level of hardware requirements along with quarterly requirements of minimum level and refurbished hardware. Graphic representation is provided for minimum level of hardware required, superimposed on the cumulative graphic output of new hardware requirements. BIGMAC also can provide graphic representation of cumulative and non-cumulative requirements for new and refurbished hardware. To increase output clarity, BIGMAC is designed so that when providing graphic output, the smallest possible scale is used. One of the capabilities of this versatile program includes consideration of DDT&E hardware quantities to determine the latest possible year to resume production after a production gap, and to continue production at a constant rate. A generalized program flowchart including a brief functional synopsis of each of the required subroutines follows.

BIGMAC - General Program Flowchart



The general descriptions of each of the eleven subroutines used in the program BIGMAC are listed below.

SUBROUTINE	DESCRIPTION
DRAXIS	Determines window size and draws X and Y axes.
LABEL	Displays proper labels on the screen, describing the graphic representation that will be drawn.
MARKER	Determines the scale to be used and marks the axes.
REGPLT	Presents graphic representation of the analyzed output quantities in the form of a Step Chart.
BARPLT	Presents the graphic representation of the analyzed output quantities in the form of a histogram.
MINPLT	Presents the graphic representation of the analyzed output quantities in the form of straight lines.
BOSIM	Performs the required calculations to determine new hardware quantity requirements.
REFURB	Performs calculations to determine the refurbished hardware quantity requirement.
MINIMUM	Determines the minimum yearly requirement of new hardware.
BREAK	Provides quarterly breakdow of yearly hardware requirements.
HRDCPY	Determines the need for a hard copy.

APPENDIX D

COST PER FLIGHT PROGRAM FLOW AND DESCRIPTION

PROGRAM DESCRIPTION

This Cost Per Flight Program flow diagram has been designed to provide the user with a program flow for cost analysis using the cost per flight computer program.

The CPF program algorithm was written in the Fortran IV programming language. It was originally designed for execution on the IBM 7044 and the UNIVAC 1108. It was modified to execute on the PDP 11/70.

The CPF program evaluates the cost elements, hardware and non-hardware, and determines for each element, the total cost, the average unit cost and an average cost per flight.

The CPF program outputs cost data in a concise and legible form for user interpretation. For each hardware element costed, the total cost of new units, refurb units and spare units, by development phase and by operational phase is presented in tabular form.

PROGRAM INPUT

The input data has been divided into three sections, program control data, non-hardware or line item data, and subsystem hardware data. Each section is discussed as follows:

Program Control Data –

The program control card is a single card containing several parameters that effect cost analysis of all line item cost data and all subsystem hardware cost data. For each data set, the user may specify a maximum of three unique time periods (fiscal year/quarter) for which the output cost results are standardized. If all time periods are omitted or an invalid time period is used, the cost results are standardized to FY 72/3. Growth and Reserve factors are also entered on the program control data card.

Line Item Cost Data –

The purpose of this input section is to enable the user to cost elements, such as Assembly, Project Management, etc., that are non-hardware or direct cost, and to record the cost results as unique line item entries in specific program output reports.

Subsystem Hardware Cost Data —

The subsystem hardware costing is divided into three cost categories, new units, refurbishable units, and spare units. Table 7 of the Cost Per Flight Program Description and User's Manual presents a card listing of sample hardware cost data and Table 8 identifies input criteria for each of the hardware cost parameters.

PROGRAM OUTPUT

Program output is printed in four parts: inflation rate tables, input data, cost totals and averages, and special report tables. Each is discussed below.

Inflation Rate Tables —

Unless the user specifies otherwise, a table of the inflation rates currently used in the program is printed.

Input Data —

To facilitate editing of the input data, and to record data used in generating specific cost results the program outputs cost analysis input data in a concise and legible form for user interpretation. Also printed is the Adjusted TFU (input TFU inflation or deflated including program growth and reserve factors).

Cost Total and Average Unit Cost —

This section of the program output presents the cost total and average unit cost for each subsystem hardware input element. The cost results for the new hardware, refurbished hardware, and spare hardware are printed separately for the development phase and for the operational phase.

Special Report Tables —

These tables contain basically the same data previously output, except the data is reformatted and isolated for different reports.

SUBROUTINE SUMMARY

There are only four subroutines in the Cost Per Flight program. A majority of the code is contained in the main program. The subroutines used in the CPF program are summarized as follows:

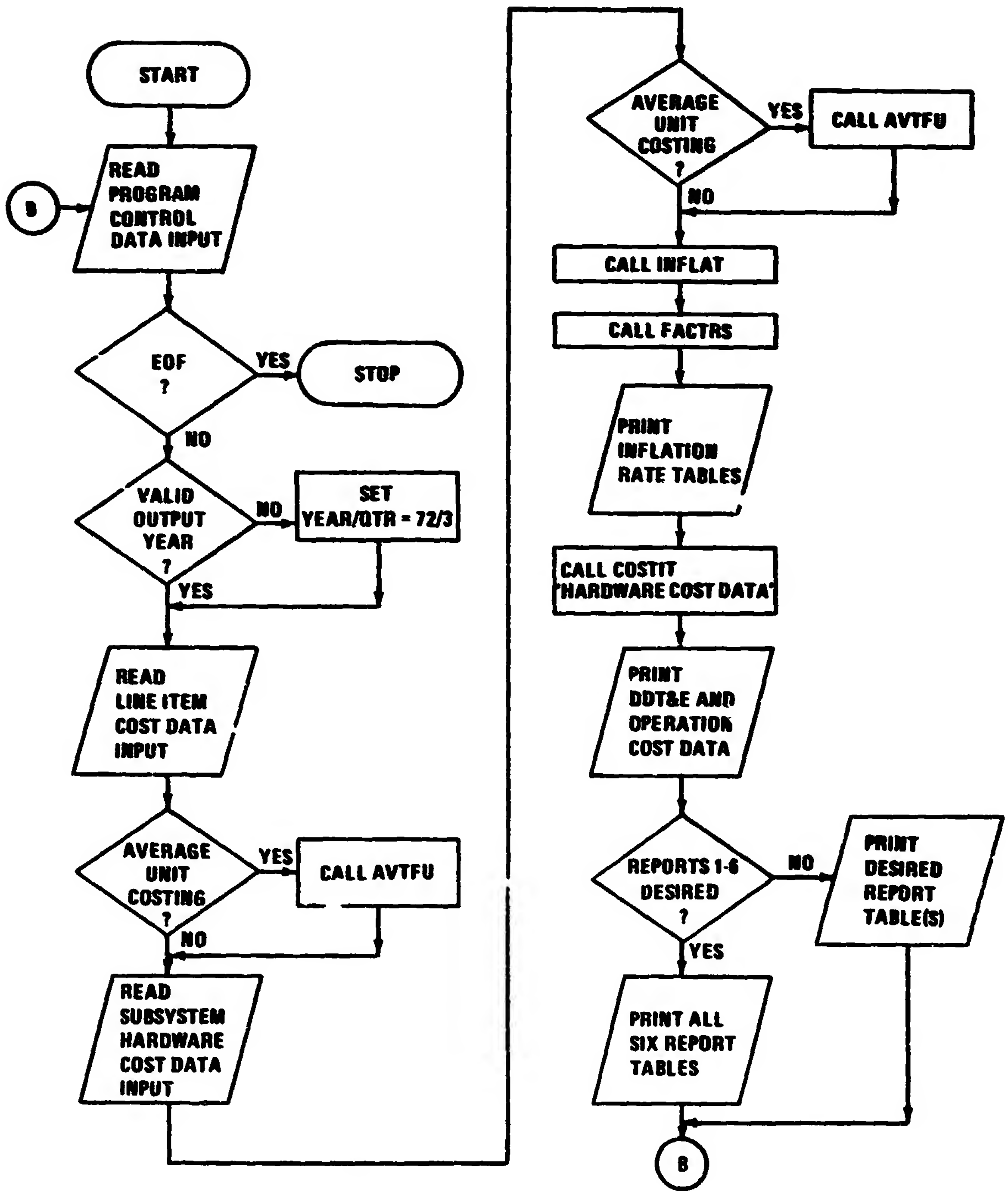
AVTFU — Given the average cost of a number of units, the Theoretical First Unit cost is computed.

COSTIT — Given the TFU and the number of units to be costed, the total cost of these units is computed.

FACTRS — This subroutine includes the program growth and reserve factors in the cost value.

INFLAT — This subroutine deflates or inflates the input cost data. Included in INFLAT are inflation rates for the years 1972 to 1990 by quarters. The annual inflation rate is figured compounding the quarterly rates.

CPF PROGRAM FLOWCHART



APPENDIX E

ANNUAL COST PROGRAM (ACP)

INTRODUCTION

This summary is designed to provide the nonprogrammer with a description of how the Annual Cost Program (ACP) operates. The ACP was developed to aid in the cost-per-flight evaluations for the SRB project and in particular to provide real year cost budget estimates.

There are three basic input requirements for the ACP:

1) Work Breakdown Structure (WBS)

2) Cost data for each WBS element

3) Procurement and delivery schedules for each WBS element.

The Annual Cost Program (ACP) is a FORTRAN V algorithm currently operational on the Univac 1108 Exec 8 computer system. The ACP performs cost analyses on elements of a WBS. The results are then summed to obtain costs of the higher order elements within the WBS. Originally designed to be general in nature, the current version has been developed to cost strictly for the SRB Project. However, the program has been segmented to allow modifications to reflect changes in the WBS, input lists, or project.

The ACP outputs cost analysis data in a concise and legible form for user interpretation. For each element of the WBS, a summary of the units delivered or purchased, refurbishment schedules, spare hardware quantities, and other nonhardware items are presented in a table with yearly breakouts from 1977 to 1992. For each year, the unit and cost data are tabulated and summarized to make the check of input data as easy as possible. It is this breakout by year that makes the ACP a valuable tool in large project cost efforts.

WORK BREAKDOWN STRUCTURE

A WBS is a family tree subdivision of effort required to achieve an objective. The WBS is developed by starting with the objective required and successively subdividing it into manageable components in terms of size and complexity. An example structure would be program, project, system, subsystems, components, tasks, subtasks, and work elements. The WBS should be product or task oriented and should include all the necessary effort which must be undertaken to achieve the objective.

The WBS presented in Figure E-1 is representative of the version modeled in the ACP. There are four levels of depth in this WBS, although five levels are allowed. The WBS code number is the key to determination of the level of a WBS element. Block number 30 is a level three item, its code number being 1.4.4. Block number 46 is a fourth level item, its code number being 1.9.2.1.

The ACP performs cost summations by using the work breakdown structure organizational chart. The program sums the costs for the lowest level items first, storing the totals in the next higher level element. It proceeds up through the WBS performing these calculations until numbers for the highest level items have been calculated. Program results are then printed in a user specified format.

ACP COST ANALYSIS

The Space Shuttle Program has been divided into three distinct phases. During the first phase (Increment 1) the six Design, Development, Testing, and Engineering (DDT&E) missions will be flown. During Increment 2, the next 21 missions will be flown, and during Increment 3, the remainder of the shuttle missions will be flown. The ACP is designed to allow data input by increment. The input categories are:

Increment 1	Nonhardware New Hardware
Increment 2	Nonhardware New Hardware Refurbished Hardware Spare Hardware
Increment 3	Nonhardware New Hardware Refurbished Hardware Spare Hardware

Increment 1 costs do not include refurbished and spare hardware since such a requirement has yet to be identified.

The user supplies the theoretical first unit (TFU) cost, the cost analysis key, the learning curve slope if needed, and the unit delivery or production schedule for each required category within the WBS element. The cost key determines the method to be used in the cost analysis. The cost keys currently in the model are

1 C.O.D. Crawford Learning Curve

2 Constant Cost per quarter

3 C.O.D. Constant Cost per unit

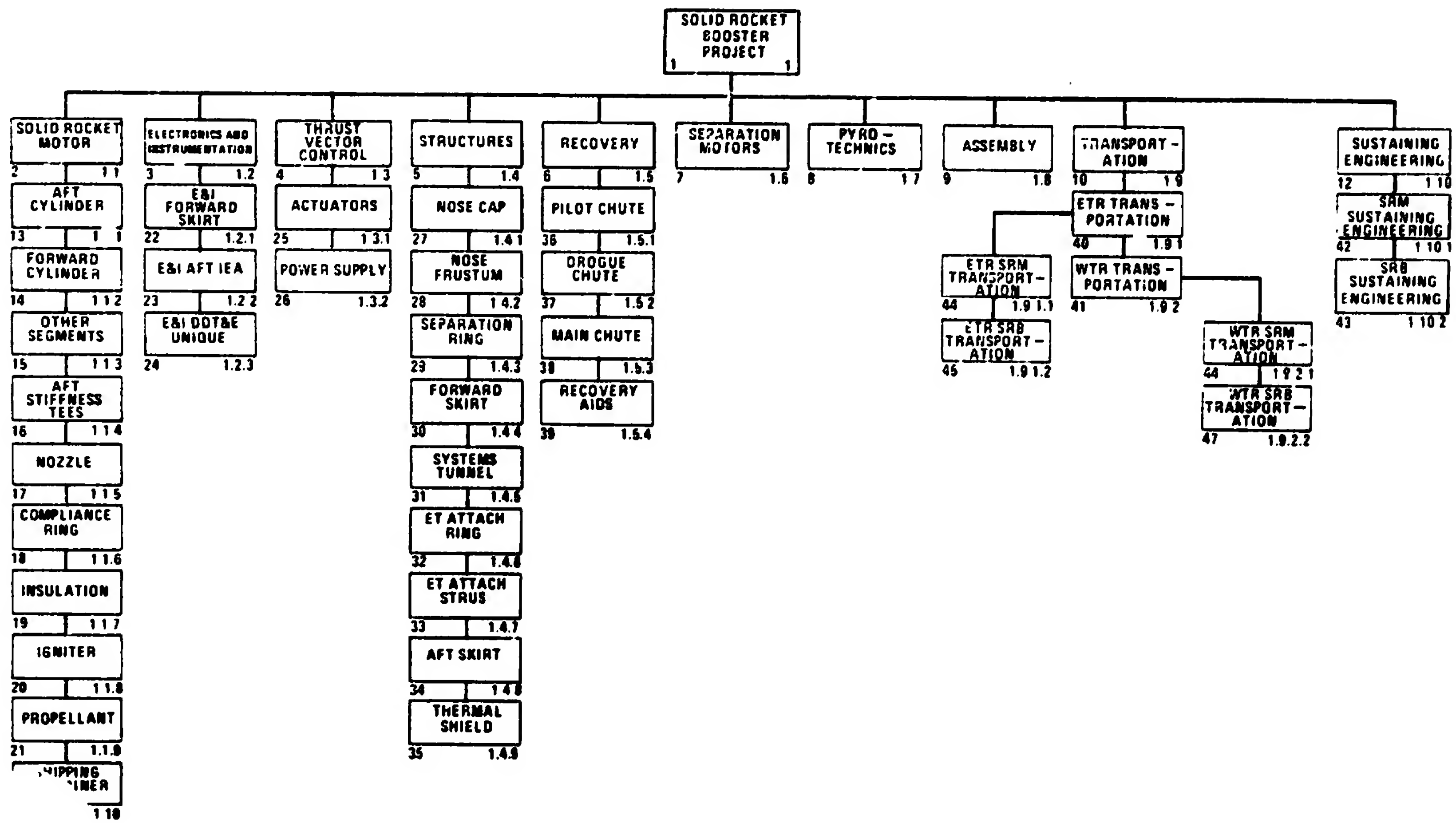


Figure E-1. Work Breakdown Structure for the Solid Rocket Booster project.

4 Direct input costs

5 Incurred Crawford Learning Curve

6 Incurred Constant Cost per unit

7 C.O.D. Wright Learning Curve

8 Incurred Wright Learning Curve

C.O.D. means cash on delivery and implies that units produced are paid for on delivery. Incurred means that units produced are to be paid for on a predetermined payment schedule prior to delivery. The payment schedule, or cost spread schedule, is an input and can be different for each input category within a WBS element.

The final user supplied data required for the cost analysis is a unit delivery or production schedule which consists of specifying the number of units delivered or purchased for each quarter of the model. The cost analysis routine applies learning curves and inflation to obtain element costs by quarter.

INFLATION

The ACP inflates all costs to provide results in real year dollars. An option exists that allows the inflation routine to deflate or inflate costs to a constant or base year dollar provided by the user.

The calendar and fiscal year relationships are provided with a quarterly breakdown of each. The inflation rates are in percent per quarter. The inflation factor is the conversion factor that changes dollars from one base year to another to account for the inflation.

The cost after inflation from FY 1972/3 can be determined by multiplying the initial cost by the inflation factor. To determine the inflation factor between any two quarters, divide the later quarter by the earlier quarter.

LEARNING CURVES

The learning curve theory states that as units on a production line are produced, the time, and subsequently the cost, to produce them decreases. The learning curve is used in the ACP to simulate production line cost decreases.

The ACP uses two types of learning curves in the cost analysis, the Crawford and Wright methods. The Crawford Curve is based on the theory that each time the total quantity of units produced is doubled,

the hours or cost to produce the last unit of this doubled quantity will be reduced by a certain percentage. The Wright Curve is based on the theory that each time the production of a product doubles, the new cumulative average cost, hours, or some other measurement declines by a fixed percentage. The percent reduction in both cases is defined as the learning curve slope.

PROGRAM GROWTH AND RESERVE FACTORS

Program growth and program reserve factors allow the user to uniformly increase cost estimates for reasons which may not be incorporated in the raw cost data. The growth factor is multiplied by each line item in the WBS summary tables. The reserve factor is applied to each yearly subtotal. The reserve cost is printed, then the sum of yearly cost and reserve cost is printed as TOTAL.

ACP SUBROUTINE DESCRIPTION

The ACP consists of one main routine and 17 subroutines written in FORTRAN V for use on the Univac 1108 computing system. The accompanying flowchart represents the logical flow of the program and is meant to help provide an understanding of the ACP's operation. More detailed input descriptions may be obtained from the references provided.

DRIVER is the main routine. It opens files for program use and calls the subroutines in the proper order.

WBSIN reads the WBS heirarchy and WBS dictionary, then stores the data on random access mass storage (FASTRAN) file 8.

INFLAT calculates the inflation tables to be used and stores the values in the appropriate arrays.

DATRAN reads and stores (on file 8) program options and costing data for each WBS block. The block data (which is subsystem data) includes TFU's, cost methods, print options, learning curve slope, start unit, cost spread functions, and delivery schedules.

INPLST prints the TFU modification factors and the inflation table specified for each WBS block.

INFTAB prints the inflation tables.

PROSCH calls the subroutines INPLST and INFTAB. PROSCH also prints cost input data in tabular formats. The data printed includes cost method, learning curve slope, start unit, input TFU, adjusted TFU, and number of units to cost. The cost spread functions are also printed for subsystems which use the incurred costing method.

SCHEDL is called by PROSCH to list the delivery schedule for each WBS block. The schedule is either hardware units required by quarter or predetermined (direct) costs by quarter, depending on the cost method being utilized.

COSTAN calculates the costs for each WBS block using the information previously read and stored. The output from this subroutine is stored on F8.

SUM reads the results on F8 and sums the data for each level of the WBS, stores the sum in the appropriate block, and writes the results on F8.

OUTPUT controls the printing of results. Individual block summaries can be printed by quarter, by year, and by total. Summary tables, in which the input blocks are defined by the user, are also printed by OUTPUT.

QTROUT is called by OUTPUT to print quarterly summary tables.

TBLSUM is called by OUTPUT to sum the results listed in the summary table over the entire mission model (FY 1977 through FY 1994).

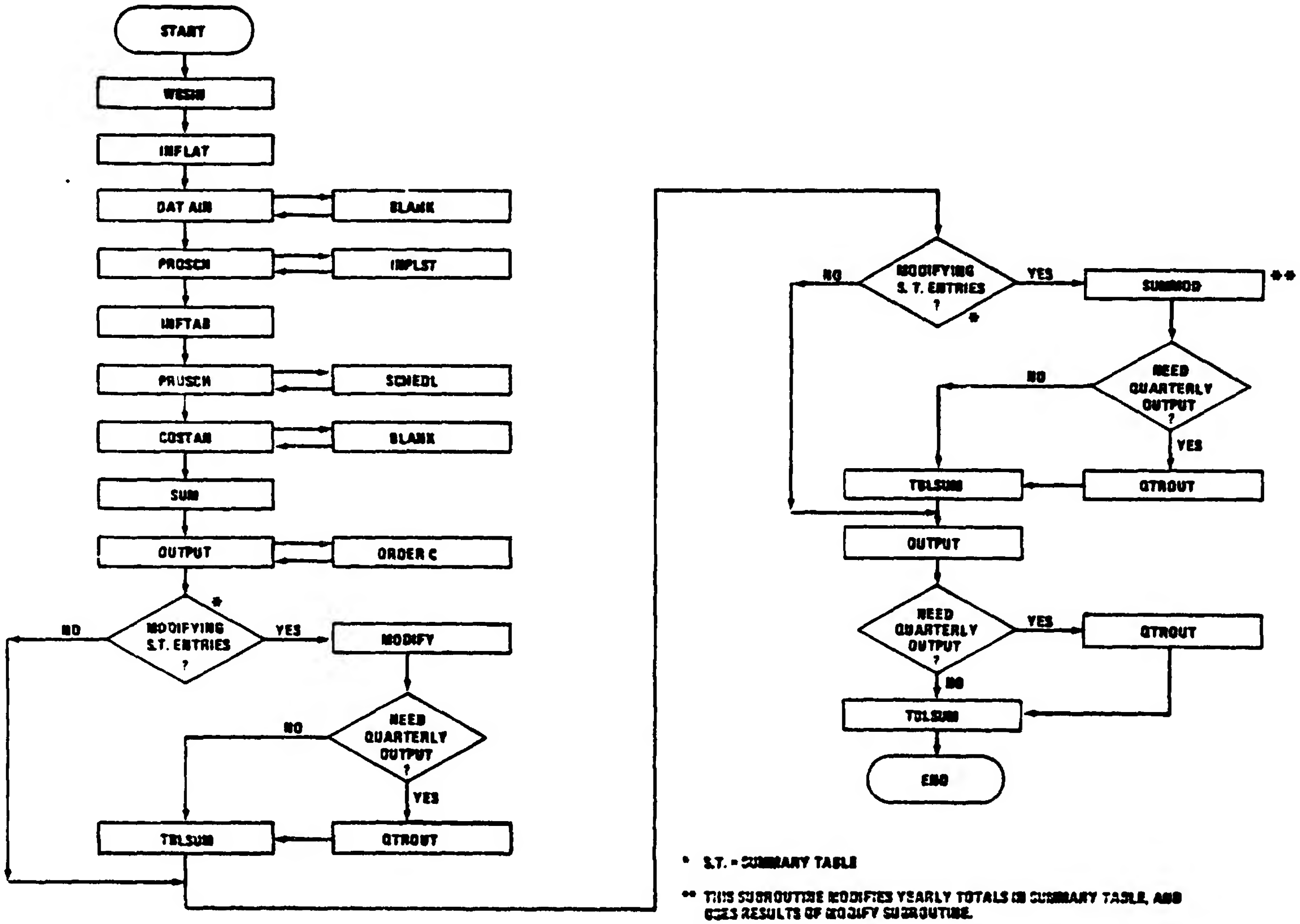
MODIFY is called by OUTPUT when the user specifies all summary table entries to be modified by user specified factors.

SUMMOD applies user specified factors to the results of the MODIFY subroutine to further modify summary table values.

ORDERC is called by OUTPUT and orders the blocks based on total block cost. A table is then printed showing block name, ranking, block cost, the block's percentage of total cost, cumulative [illegible] and cumulative percentage.

BLANK is called by several subroutines to "zero-out" array values prior to calculation of new values which are then stored on F8.

ANNUAL COST PROGRAM (ACP) FLOW DIAGRAM



* S.T. = SUMMARY TABLE

** THIS SUBROUTINE MODIFIES YEARLY TOTALS IN SUMMARY TABLE, AND USES RESULTS OF MODIFY SUBROUTINE.

APPROVAL

SPACE SHUTTLE SOLID ROCKET BOOSTER COST-PER-FLIGHT ANALYSIS TECHNIQUE

By J. Alan Forney

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

H. E. Thomason

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Director, Systems Analysis and Integration Laboratory

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